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Title of Thesis: **Stratigraphy and Sedimentology of the Pleistocene Ironshore Formation at Rogers Wreck Point, Grand Cayman: A 400 ka Record of Sea-Level Highstands**

Degree: **Master of Science**

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I am sufficiently proud of my knowing something to be modest about my not knowing it all.

– *Vladimir Nabokov*

UNIVERSITY OF ALBERTA

STRATIGRAPHY AND SEDIMENTOLOGY OF THE PLEISTOCENE IRONSHORE FORMATION AT ROGERS WRECK POINT, GRAND CAYMAN: A 400 KA RECORD OF SEA-LEVEL HIGHSTANDS

BY

JENNIFER LYNN VÉZINA

A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

DEPARTMENT OF EARTH AND ATMOSPHERIC SCIENCES

EDMONTON, ALBERTA

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UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Stratigraphy and Sedimentology of the Pleistocene Ironshore Formation at Rogers Wreck Point, Grand Cayman: A 400 ka Record of Sea-Level Highstands** submitted by **Jennifer Lynn Vézina** in partial fulfillment of the requirements for the degree of **Master of Science**.

To Vera Fortin, who opened my eyes to the opportunities that awaited.

Abstract

Core recovered from 14 wells at Rogers Wreck Point shows that the Ironshore Formation encompasses four unconformity-bound members. In ascending order, these are members A, B, C, and D. The unconformities are commonly highlighted by caliches and/or *terra rossa*.

Seven Th/U dates from aragonitic corals indicate that Member A formed >400 ka BP, Member B ~346 ka BP, Member C ~229 ka BP, and Member D ~131 ka BP. These ages correlate with the highstands of the last four interglacial periods. As such, they probably represent Marine Isotope Stages 5 (Member D), 7 (Member C), 9 (Member B), and 11 (Member A). Assuming Grand Cayman has been vertically tectonically stable for the last 500 ka, the elevation of sea-level at the time of deposition of each unit relative to present sea-level was: Member A, -5.7 m; Member B, +0.5 m; Member C, +1.1 m; and Member D, +6.0 m.

The limestone units, which have similar biotic and lithologic characteristics, represent deposition that took place on a narrow coastal shelf. Deposition was controlled by repeated highstands and lowstands of sea-level. The facies (grainstone, rudstone, packstone-wackestone-mudstone, head coral, and branching coral facies) in each unit indicate shallow-water regimes for each sequence. Member A, with its high diversity of fauna, was deposited in open-marine conditions. Members B, C, and D were deposited in quiet-water lagoons which probably had fringing reefs at their seaward edges. Member B contains numerous head corals, Member C has abundant branching corals, and Member D has an abundant and diverse mix of fauna at its seaward edge.

ACKNOWLEDGMENTS

Well, after, three years, it's finally done, and it didn't turn into a "Jen story" - it actually has an ending! Any brevity and clarity in this work are thanks to my supervisor, Dr. Brian Jones, who edited, and edited, and edited, ... you get the idea.

Thanks to my fellow Winkie drillers, Ian Hunter, Kenton Phimester, and Brent Wignall. Without them I never would have (1) learned the proper method of applying pipe dope as sunscreen, (2) drilled in a lightning storm while attaching ten-foot lengths of pipe and standing in two inches of water, and (3) had the opportunity to experience the shrill musical notes of a penny whistle over the noise of the drill.

Thanks to a great group of people with whom I shared an office at some point during my stay in Edmonton: the 'Smelly Boys', Ian Hunter, Kenton Phimester, Paul Blanchon, Chun Li, Bill Kalbfleisch, Brent Wignall, Leo Piccoli, David 'Dayve' Hills, and Jason 'Tex' Montpetit. Hey, if you ever need to know the truth, I'm there for you. The arrival of the two newest additions to the Carbonate Group, Betsy 'Hurricane Girl' Willson and Astrid Aarts, mysteriously coincided with an increase in the amount and volume of conversation in the office, as well as the infamous squeeze-cheese wars. The boys may never recover.

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In addition to those already mentioned, I'm grateful for the support, encouragement, and camaraderie offered by Mark 'the sponge' Hearn and Karen Fallas. I am also

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CHAPTER I:
INTRODUCTION

1.1 Introduction

The Pleistocene epoch is notable for cyclic glaciations that resulted in fluctuating sea-levels. Evidence of sea-level change is most evident on tectonically-uplifted islands of the tropics (*e.g.*, Barbados, Papua New Guinea), where successions of coral terraces, each representing a highstand, have formed. Radiometric dating of corals from the terraces enabled uplift rates to be determined, and combined with facies interpretations led to sea-level estimates for individual terraces. Marine terraces from the last major interglacial ~130 ka BP are the most commonly studied because they are widely exposed throughout the Caribbean. Older terraces exist, but lengthy exposure to meteoric processes has diagenetically altered the corals and accurate dates cannot be obtained. On Barbados, for example, elevated terraces provide exposures through strata that are up to 500 ka old.

Mapping of Pleistocene exposures in the Caribbean has shown that they typically consist of a sandy lagoon with patch reefs (if water depth permits), a reef crest community dominated by *Acropora palmata*, and fore-reef debris (Mesollela, 1967; Mesolella *et al.*, 1970; James *et al.*, 1971). This geometry is similar to that of modern reefs in the Caribbean, including those surrounding Grand Cayman (Rigby and Roberts, 1976; Hunter, 1994; Blanchon, 1995).

This study examines subsurface data from the Pleistocene Ironshore Formation at Rogers Wreck Point on Grand Cayman (Figure 1.1). Limestones in the Ironshore Formation still have much of their original aragonitic composition. This unique situation has permitted radiometric dating of strata that elsewhere are too diagenetically altered to obtain accurate dates.

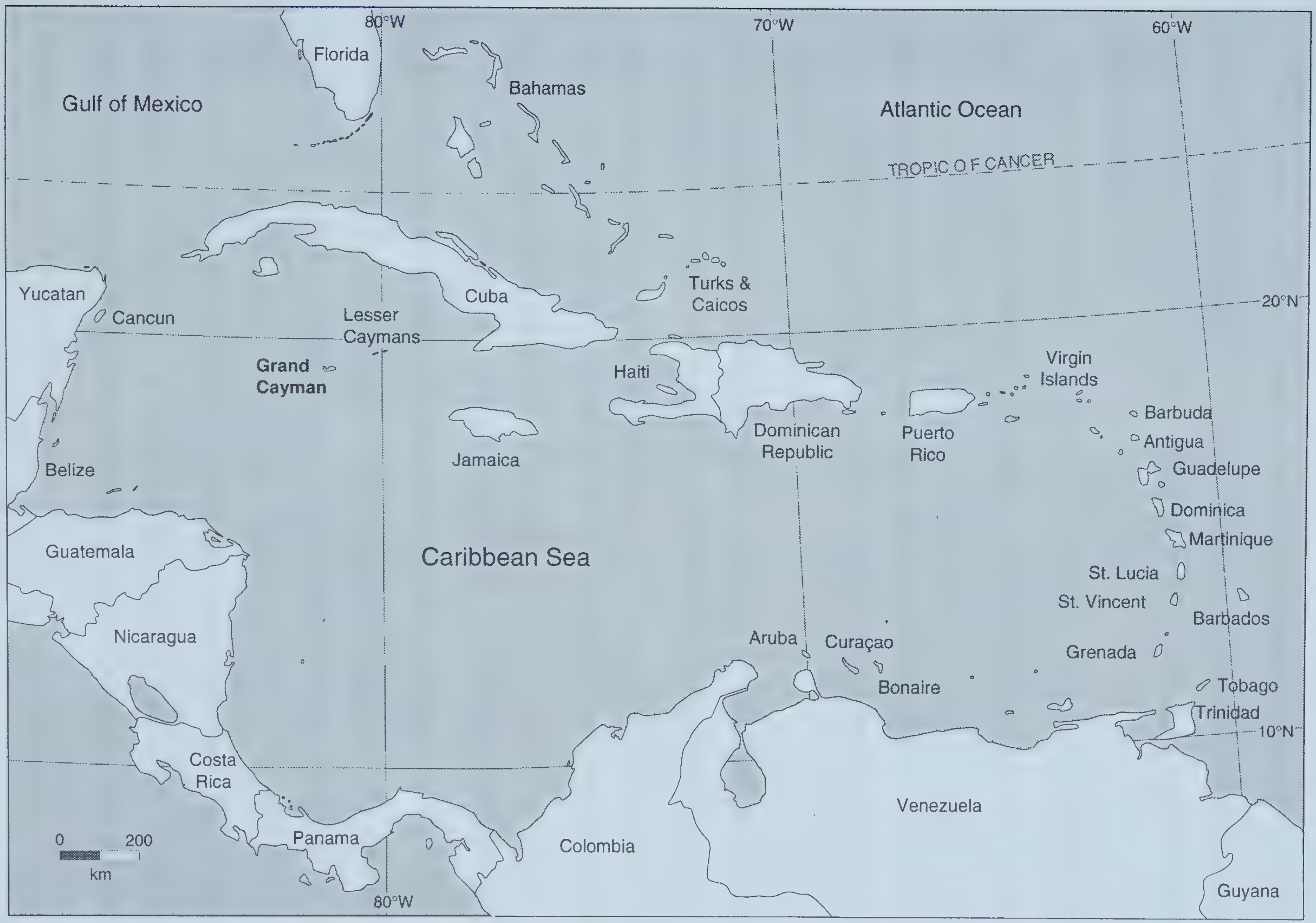


Figure 1.1. Location of the Cayman Islands in the Caribbean.

1.2 Geologic and Geographic Framework

1.2.1 Location and Geography

The Cayman Islands are located in the northwest Caribbean, south of Cuba and northwest of Jamaica (Figure 1.1). Grand Cayman, the largest of the Cayman Islands, is 35 km long (east-west), 14 km wide in the west, and 6 km wide in the east. The total land area is ~197 km^2.

Most of Grand Cayman is <3 m above sea-level (asl). In general, the west half of the island is lower than the east half of the island. The brackish water mangrove swamps that cover low-lying land (Mather, 1972) are breeding grounds for hoards of mosquitoes. The remaining land surface encompasses a rugged karst terrain with patchy red soils (*terra rossa*) and dense vegetation (Jones and Smith, 1988), land cleared for agriculture, and urban areas.

The Mountain has the highest elevation on Grand Cayman at 18 m asl. The only other significant landform is a discontinuous peripheral ridge that parallels the north, south, and east coasts of Grand Cayman (Jones and Hunter, 1994). This ridge, which attains a maximum height of ~12 m asl in the east end, is more subtle in the western part of the island where it has elevations of 3-5 m asl.

Despite several kilometres of palm-shaded, white sand beaches, Grand Cayman's best scenery is below sea-level. Fringing reefs parallel the north, east, and south coasts of the island, but are conspicuously absent off the western leeward coast. The fringing reefs are growing primarily at an abrupt break in slope marking the edge of a shallow (3-10 m deep) terrace that surrounds Grand Cayman (Rigby and Roberts, 1976; Roberts, 1976, 1977; Smith, 1988; Ghiold and Smith, 1990; Hunter, 1994; Blanchon, 1995). A second, deeper terrace (18-25 m deep) on the outer shelf also supports a diverse biota (Rigby and Roberts, 1976; Roberts, 1976, 1977; Smith, 1988; Ghiold and Smith, 1990; Hunter, 1994; Blanchon, 1995; Blanchon and Jones, 1995).

In several places the fringing reefs have small coastal lagoons behind them, and many of these contain patch reefs. The coastal lagoons are ~250 m to ~1.25 km wide, and generally <3 m deep. North Sound, the large, prominent lagoon on the island, is ~10 km in diameter and on average less than 5 m deep (Roberts, 1976).

1.2.2 Tectonic Setting

The Cayman Islands are located in one of the most tectonically active areas in the Caribbean Sea (Figure 1.2). The islands are high points along the Cayman Ridge, which forms the northern margin of the Cayman Trench. The ridge is the westward submarine extension of the Sierra Maestra Mountains of Cuba; it extends to within 100 km of the continental shelf of Belize and then disappears below sediment cover (Falquist and Davies, 1971). Seismic data from the western portion of the ridge led Falquist and Davies (1971) to suggest that block faulting lifted the structure over 1500 m above the Yucatan Abyssal Plain to the north and the Cayman Trench to the south.

The Cayman Ridge was predominantly a shallow carbonate bank (Perfit and Heezen, 1978) until Oligocene-Miocene subsidence began at rates of 6 cm/10^3 yr (Perfit and Heezen, 1978) to 10 cm/10^3 yr (Emery and Milliman, 1980). Emery and Milliman (1980) recovered shallow water Oligocene carbonates from the north wall of the Cayman Trench at depths of 3.1 km. The carbonates cap metavolcanics which in turn overlay metamorphic and plutonic rocks, predominantly granodiorite (Emery and Milliman, 1980). In post middle-Miocene times, localized uplift continued to elevate Central America, the Swan Islands, the Cayman Islands, Jamaica, and most of southern Cuba above sea level, whereas adjacent crust continued to subside (Perfit and Heezen, 1978).

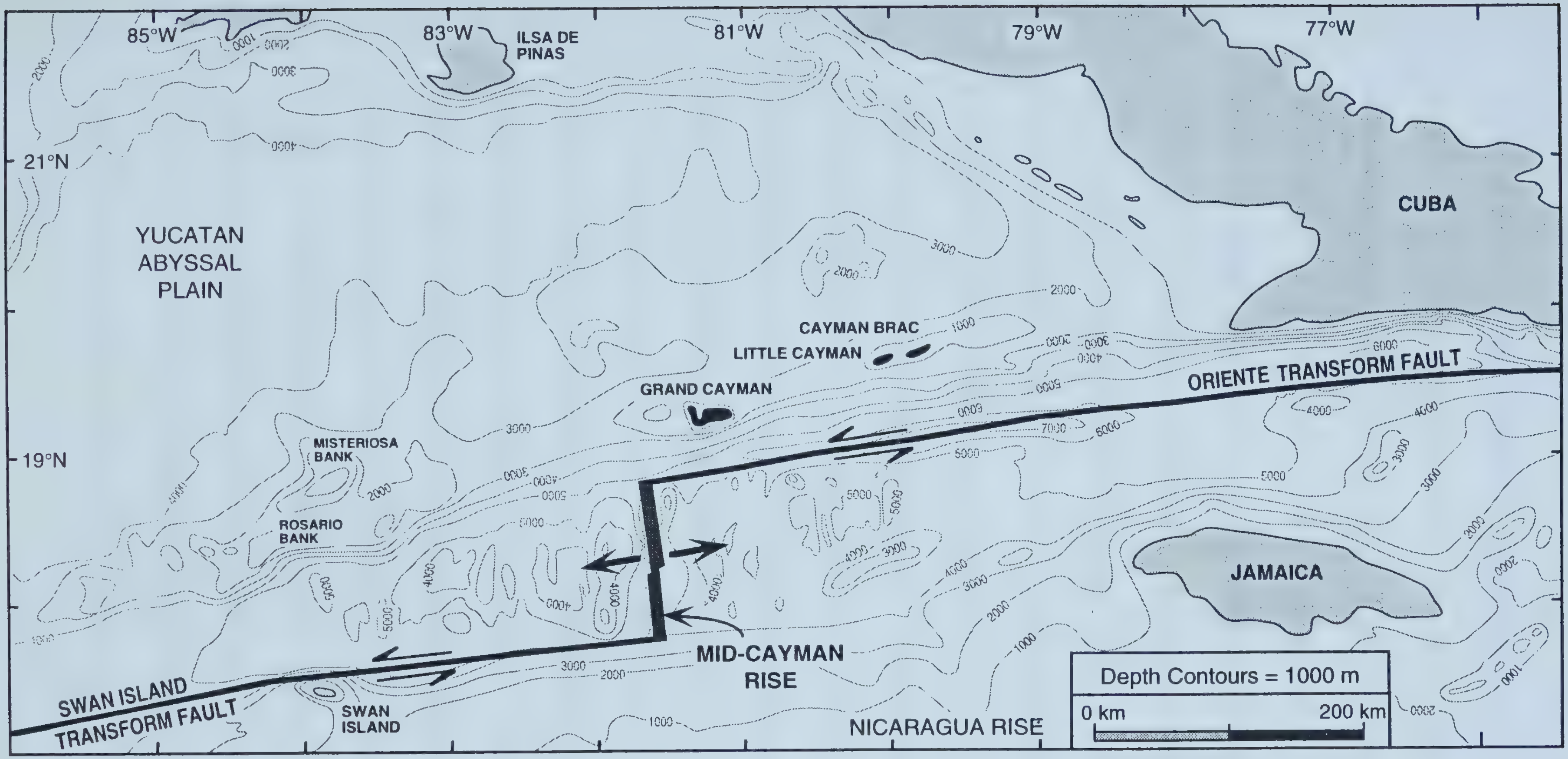


Figure 1.2. Tectonic setting of Grand Cayman and bathymetry of the Cayman Trench and surrounding area (adapted from Pleydell *et al.* (1990); based on information from Perfit and Heezin (1978) and MacDonald and Holcombe (1978)).

In contrast to the Cayman Ridge are the great depths of the Cayman Trench. Within 10 km of the south coast of Grand Cayman water depths are >4000 m. Bound to the north by the Cayman Ridge and to the south by the Nicaragua Plateau, the trench is 100-150 km wide (MacDonald and Holcombe, 1978), reaches depths in excess of 7000 m (MacDonald and Holcombe, 1978; Stoddart, 1980), and extends over 1600 km from the Windward Passage (between Cuba and Hispaniola) to the Gulf of Honduras (Perfit and Heezen, 1978). The Cayman Trench is an extensional feature that was generated in the Early Tertiary through easterly drift (relative to North America) of the Caribbean Plate (Bowin, 1968; Perfit and Heezen, 1978). Left-lateral motion took place on the eastern part of the northern wall (the Oriente Transform Fault) and on the western part of the south wall (the Swan Island Transform Fault). A series of north-south oriented ridges and valleys, in the center of the trench, reflect the formation of new ocean floor at the Mid-Cayman Rise (Holcombe *et al.*, 1973). Spreading estimates based on thermal profiles of the trough are 15-30 mm/yr (Rosencrantz *et al.*, 1988).

The tectonic history of the Cayman Islands is poorly known. Physiographically Grand Cayman and Little Cayman are quite different from Cayman Brac, which attains heights of >40 m and is remarkable for its sheer cliffs. Little Cayman and Grand Cayman are low-lying, rarely exceeding 12 m of relief. Bedding in Oligocene carbonates exposed on Cayman Brac indicates that the island may be tilted at about 0.5° to the west (Jones *et al.*, 1994a; Jones, 1994). Miocene and Pliocene carbonates, found on all three islands, form the core of Grand Cayman, Little Cayman, and Cayman Brac. On Grand Cayman and Little Cayman, obscure bedding and the lack of marker horizons in the Tertiary strata make it difficult to determine the structure of the islands. Rigby and Roberts (1976)

suggested that the strata on Grand Cayman are nearly horizontal, but Horsfield (1975) suggested that uplift centered over the Windward Passage (between Cuba and Haiti) has resulted in a westerly tilt to all the islands. Matley (1926) also suggested that all three islands were tilted in a westerly direction, and that each island was bounded by "powerful submarine faults". Recent work suggests that the Pleistocene strata of Grand Cayman have not undergone vertical movement over the last 125 ka (Emery, 1981; Woodroffe *et al.*, 1983; Jones and Hunter, 1990; Jones, 1994).

1.3 Stratigraphy of the Cayman Islands

The Tertiary and Quaternary carbonates of the Cayman Islands were first described by Matley (1926). He noted the Pleistocene rocks formed low-relief terraces that surround and onlap the Tertiary core of each island. Matley (1926) named the Tertiary strata the Bluff Limestone and the Pleistocene rocks the Ironshore Formation. Jones and Hunter (1989), however, advocated the use of the name Bluff Formation in order to avoid the lithological connotation attached to the original name.

Recent work by Jones *et al.* (1994a; 1994b) led to a revision of the stratigraphy of the Tertiary strata on the Cayman Islands. With the recognition that the 'Bluff Formation' includes three unconformity-bound units, Jones *et al.* (1994b) named the Brac, Cayman, and Pedro Castle formations and placed them in the Bluff Group (Figure 1.3).

The Ironshore and Cayman formations outcrop on all three of the Cayman islands, but the Pedro Castle Formation has been found to date only on Grand Cayman and Cayman Brac (Figure 1.4). The Brac Formation forms the vertical cliffs on Cayman Brac.

AGE	LITHOTYPE		UNIT	LITHOLOGY	BIOTA
PLEIST.			**Ironshore Formation** *Unconformity*	Limestone	Corals (VC) Bivalves (VC) Gastropods (C)
PLIOCENE		Bluff Group	**Pedro Castle Formation** *Unconformity*	Dolostone (fabric retentive), dolomitic limestone, and limestone.	Foraminifera (VC) Corals (C) Bivalves (LC) Gastropods (C) Red algae (C) *Halimeda* (R)
M. MIOCENE		Bluff Group	**Cayman Formation** *Unconformity*	Dolostone (fabric retentive and destructive)	Corals (VC) Bivalves (LC) Rhodoloites (LC) Gastropods (R) Red algae (LC) Foraminifera (LC) *Halimeda* (R)
L. OLIG.		Bluff Group	**Brac Formation**	Limestone, or sucrosic dolostone (fabric destructive) with pods of limestone.	Bivalves (VC) Gastropods (C) Foraminifera (VC) Red algae (R)

Figure 1.3. Table of formations for the Cayman Islands (after Jones, 1994). VC = Very Common, C = Common, LC = Locally Common, R = Rare.

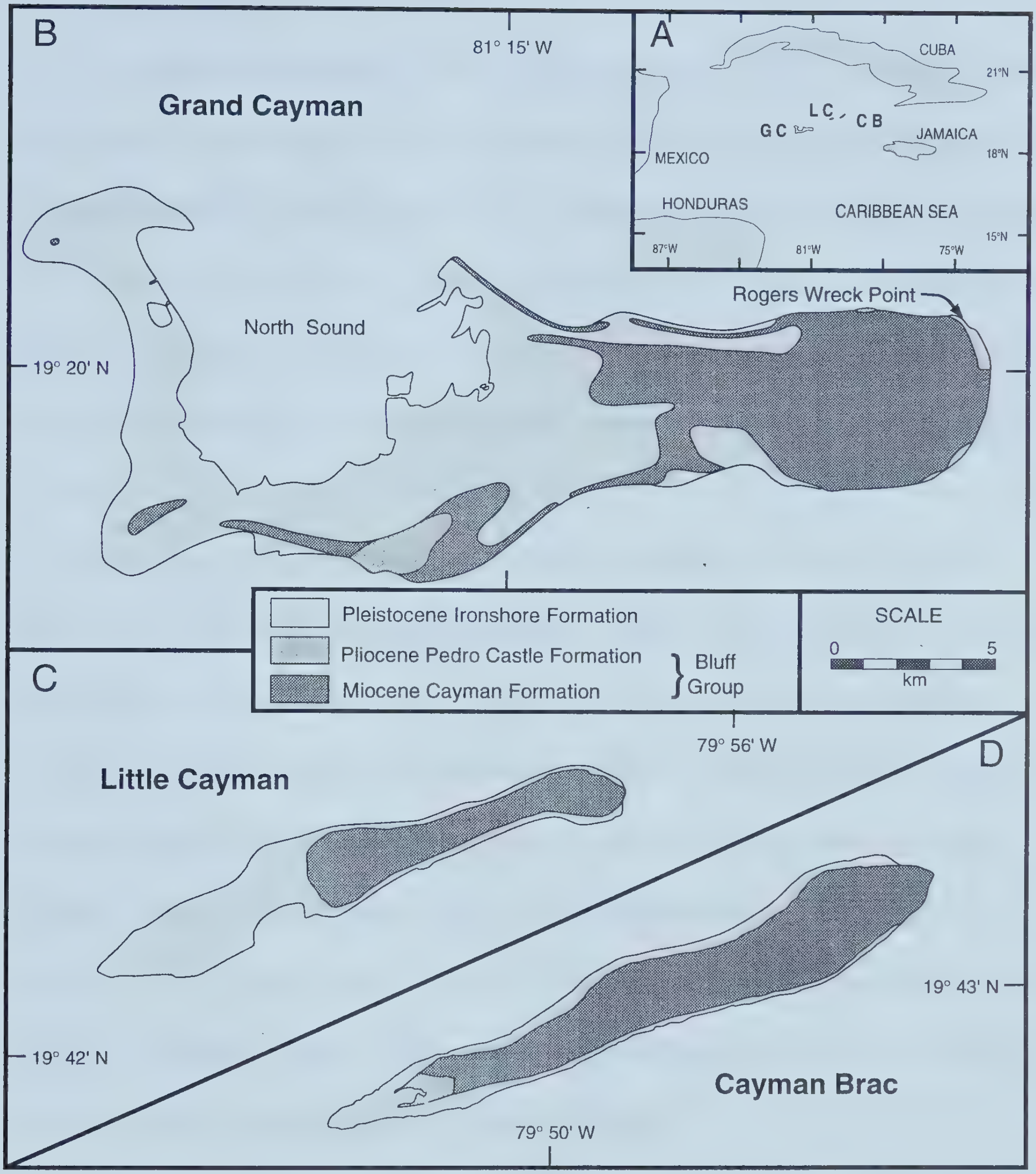


Figure 1.4. A) Location map showing the Cayman Islands, Grand Cayman (**GC**), Little Cayman (**LC**), and Cayman Brac (**CB**). B) Geological map of Grand Cayman showing study area (Rogers Wreck Point). C) Geological map of Little Cayman. D) Geological map of Cayman Brac. (Modified after Matley, 1926; Hunter and Jones, 1989)

1.3.1 Stratigraphy of the Bluff Group

Limestones and dolostones of the Tertiary Bluff Group form the resistant core of each of the Cayman Islands. The Brac Formation, with its type section on Cayman Brac, has been assigned a Lower Oligocene age of ~28 Ma based on foraminifera biostratigraphy and $^{87}Sr/^{86}Sr$ ratios (Jones *et al.*, 1994a; Jones, 1994). Wackestones and grainstones are found in un-dolomitized parts of the formation, but fabric destructive sucrosic dolostone locally obliterates texture. To date, the Brac Formation has not been located on Grand Cayman.

The Cayman Formation outcrops on all three islands and is thought to have a Middle-Upper Miocene age (Jones and Hunter, 1989; Jones *et al.*, 1994a). It is formed exclusively of fabric-retentive microcrystalline dolostones and is characterized by a wide variety of facies and an abundant, diverse fauna (Jones and Hunter, 1989; Jones *et al.*, 1994a). Outcrops of the Cayman Formation are strongly karsted, forming a rugged, irregular, pitted surface (Matley, 1926; Doran, 1954; Folk *et al.*, 1973; Rigby and Roberts, 1976; Stoddart, 1980; Jones *et al.*, 1984; Smith, 1987; Jones and Smith, 1988; Squair, 1988; Jones, 1989). The exact thickness of this unit is unknown, but drilling indicates that it is over 140 m thick on Grand Cayman.

Strontium dating of the Pedro Castle Formation indicates an age of 5-3 Ma (Jones *et al.*, 1994b); the minimum Pliocene age is confirmed by the presence of *Stylophora*, a coral that became extinct in the Caribbean at the end of the Pliocene (Frost, 1977). The Pedro Castle Formation is formed of fabric-retentive dolostones, limestones and limestones replaced to varying degrees by dolomite. The Pedro Castle Formation has been

completely removed from many areas on Grand Cayman. If present, it is unconformably overlain by the Pleistocene Ironshore Formation.

1.3.2 Stratigraphy and Depositional Setting of the Pleistocene Succession

Matley (1926), who made a brief geological reconnaissance trip to the Cayman Islands in 1924, described the Ironshore Formation (p. 355) as a "...white and cream-coloured consolidated coral-sand marl, with some limestone...". The limestone was usually friable under a hard crust, and in some places overlain by a layer of decalcified red or brown earth (Matley, 1926). Based on the numerous well-preserved coral heads and shells in the formation, and its similarity in appearance and constitution to the Jamaican Falmouth Formation, Matley (1926) suggested that the Ironshore Formation was probably Pleistocene in age. Subsequent studies of the Ironshore Formation examined the biota (Hunter and Jones, 1988; Jones and Pemberton, 1988; Cerridwen and Jones, 1991; Jones and Hunter, 1991; Hunter, 1994), facies (Brunt *et al.*, 1973; Hunter and Jones, 1988; Shourie, 1993), sedimentology (Jones and Pemberton, 1989; Hunter, 1994), ichnology (Pemberton and Jones, 1988; Jones and Pemberton, 1989), paleogeography (Hunter and Jones, 1988; Jones and Hunter, 1990), diagenesis (Spencer *et al.*, 1984; Jones, 1988; Jones and Pemberton, 1988; Rehman *et al.*, 1994), and absolute age (Brunt *et al.*, 1973; Emery, 1981; Woodroffe *et al.*, 1983). A detailed investigation of the Ironshore Formation revealed a shallowing-upward sequence that was deposited predominantly in a quiet-water lagoon that has been called the "Ironshore Lagoon" (Hunter and Jones, 1988; Shourie, 1993) (Figure 1.5). This lagoon, located on the western half of Grand Cayman,

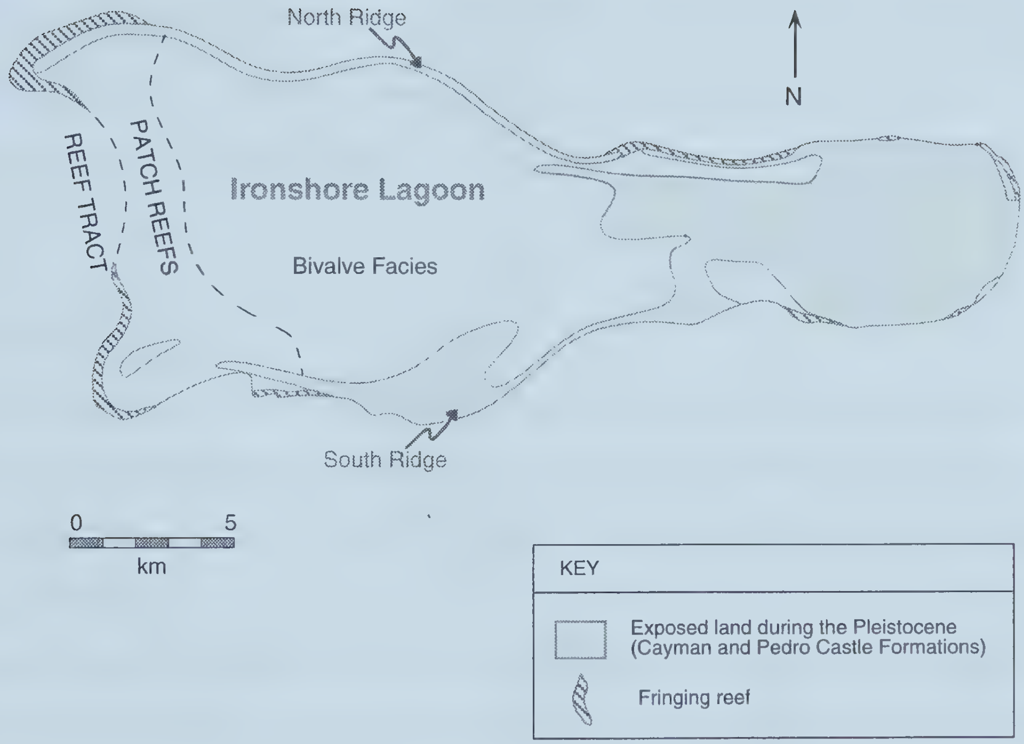


Figure 1.5. Paleogeography of the Ironshore Formation (modified from Hunter and Jones, 1988).

was protected on three sides by upstanding ridges of Tertiary dolostones to the north, east, and south and by a barrier reef to the west (Hunter and Jones, 1988).

The wells drilled at Rogers Wreck Point on the north-east coast, however, contain four caliches at distinct horizons throughout the Ironshore Formation, suggesting repeated cycles of subaerial exposure and carbonate deposition. Radiometric dates ranging from 129 ka BP to >400 ka BP support the hypothesis that four distinct units exist in the Ironshore Formation. This has important consequences for the stratigraphy and depositional history of Pleistocene strata on Grand Cayman.

1.4 Study Area

The study area, Rogers Wreck Point, is located on the north-east coast of Grand Cayman. The most prominent features of the coastline in the study area are the two rocky projections that flank Spotter Bay (Figure 1.6) and the cliffs just south of Queen's Highway (Figure 1.7).

Roughly paralleling the coast (~50-75 m shoreward) is a well-developed ridge of loose coral rubble and detritus which reaches elevations of 4.5 m above sea-level (Figure 1.7). This feature is probably a storm ridge, created by storms and hurricanes washing material onshore.

Other than the mound of storm rubble, relief between the highway and the coast is subtle. This area consists of flat terrain covered with loose sand, caliche crust, and vegetation (Figure 1.6). A few metres south of the highway, however, lie the 6-10 m high cliffs of the peripheral ridge of Tertiary strata (Figure 1.7). A distinct erosional notch is cut into the cliffs at approximately 6 m above present sea-level.

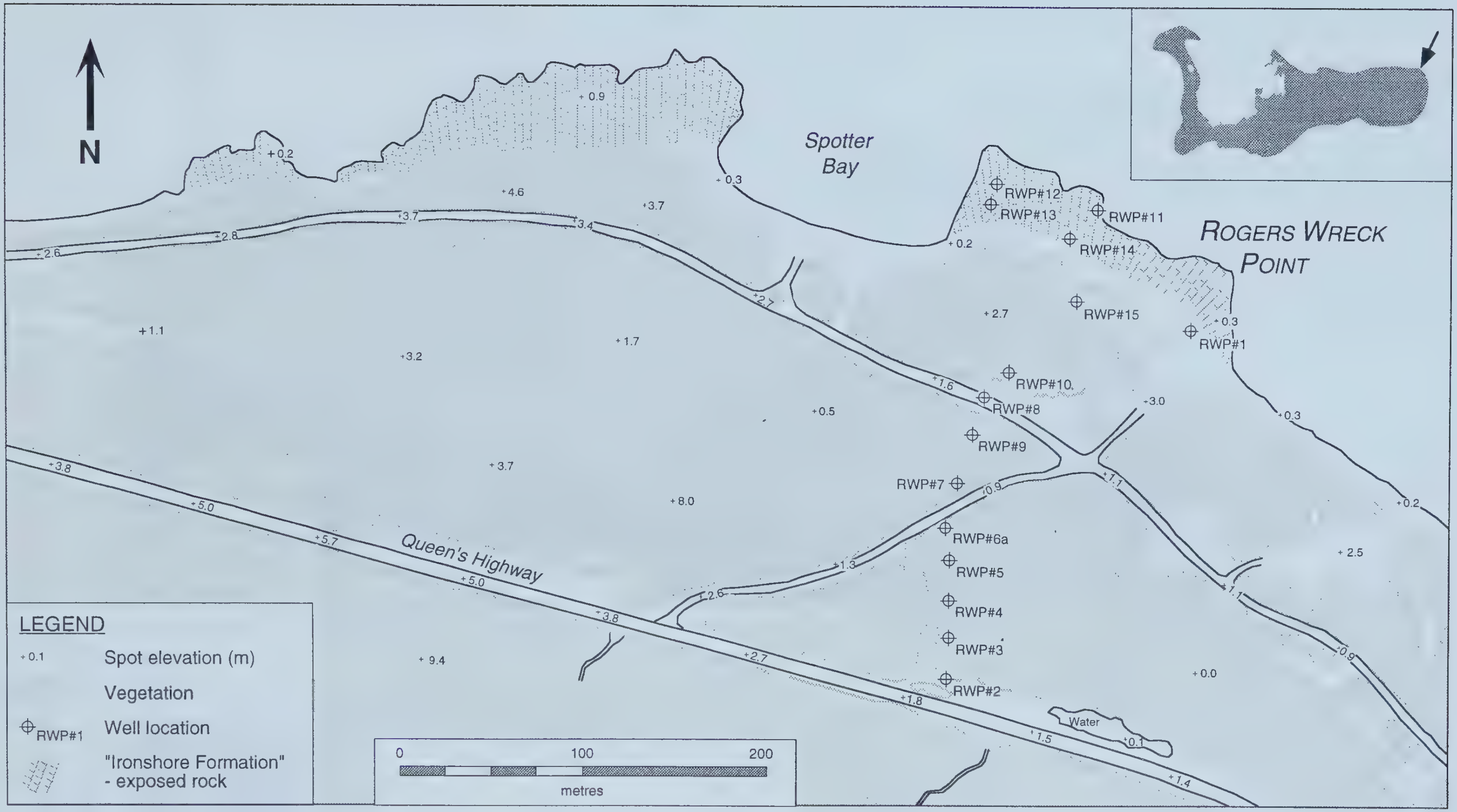


Figure 1.6. Study area and well locations at Rogers Wreck Point; inset map shows location of study area (arrow) on Grand Cayman.

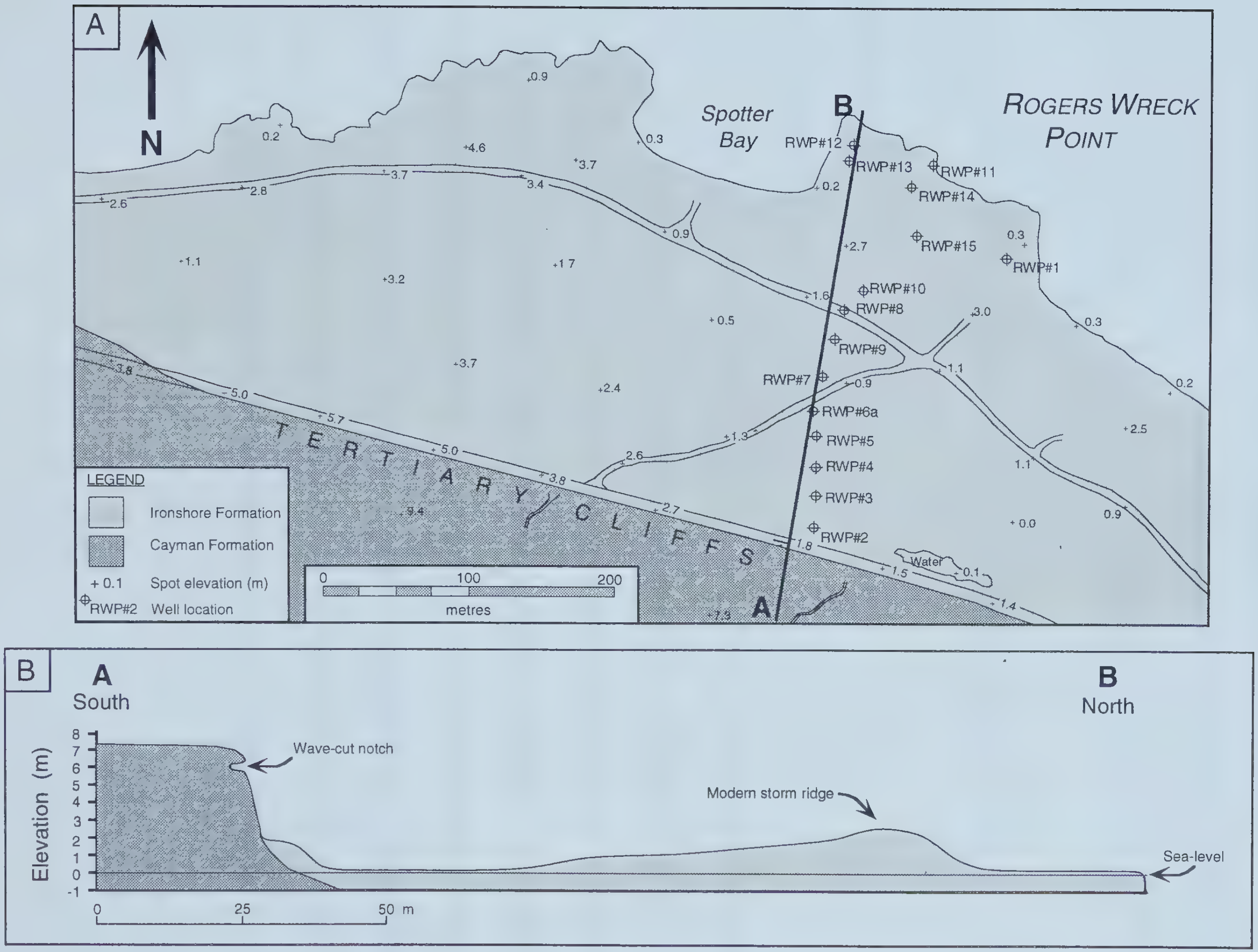


Figure 1.7. Geology (A) and topography (B) of the study area, Rogers Wreck Point.

1.5 Objectives

This study considers the Pleistocene succession on the north-east coast of Grand Cayman and will

(1) determine the stratigraphy of the Ironshore Formation at Rogers Wreck Point;

(2) describe the sedimentological characteristics of each unit;

(3) characterize facies distribution and depositional conditions for each unit;

(4) estimate sea-level elevation for each unit, and determine if they can be used as standards for the last 400 ka; and

(5) evaluate the mechanism(s) that controlled the deposition of the four units.

1.6 Methods

1.6.1 Core Retrieval

A J.K.S. Boyles' Winkie drill was used for core recovery. This portable, continuous coring diamond drill system is easily operated by three crew members. Core diameter from the drill is ~3.5 cm, and drilling depths of 122 m are possible in ideal conditions.

Sixteen wells were drilled in an approximately north-south direction at Rogers Wreck Point. Of the sixteen wells, RWP#6 was abandoned at ~4 m and RWP#12 at ~6 m because of poor hole conditions. The target depth varied for each well: the objective was to core the entire Pleistocene succession and up to 6 m of the Cayman Formation. The exception to this was RWP #2, which was drilled to ~94.8 m below present sea-level as a result of anomalously good hole conditions.

In many parts of Grand Cayman, particularly on the west side, the typically friable, unconsolidated nature of the Ironshore Formation precludes any core recovery. The fourteen wells at Rogers Wreck Point, however, had an average core recovery of 52%.

1.6.2 Core Logging

Approximately 180 m of core from 14 wells was slabbed, logged, and sampled for thin sections. Core logging was done with the intent of identifying facies, members, and evidence of unconformities in the formation; consequently greater importance was placed on texture, lithology, and grain and fossil identification, whereas diagenetic features were noted in a general sense and used on a gross scale when useful for the delineation of units. The well logs are given in Appendix 1. Core that contains mud is commonly well-indurated but grainstones are typically friable where not well-cemented; thus, most of the missing core has been interpreted as consisting of grainstones.

Embry and Klovan's (1971) modification of Dunham's classification was used to describe rock textures. Coral identification was based on comparison with plates and descriptions in Hunter (1994).

1.6.3 Radiometric Dating

Uranium is incorporated into the structure of organisms in appreciable concentrations (0.1 to 5 ppm), but Th is virtually absent. The activity of Th increases as a function of time by decay of U. As a result, aragonitic materials can be dated by measuring the activity ratio of ^{230}Th to ^{234}U; the method approaches its upper limit of dating at ~350 ka (Cherdyntsev, 1971; Ku, 1976; Schwarcz, 1980; Gill *et al.*, 1991). When subjected to meteoric diagenesis, aragonite inverts to calcite, thereby 'resetting' the dates. In order to obtain accurate figures the percentage of calcite should be less than 1% (Edwards *et al.*, 1987); this can be determined by submitting samples to X-ray powder diffraction for a

quantitative measurement of the amount of calcite present (Locock, 1992; written comm.).

Thirteen coral samples were initially selected for dating based on qualitative observations of their aragonite *vs.* calcite content. The samples were selected from a variety of depths in order to obtain dates throughout the formation. The comparison of X-ray powder diffraction results with a calibration curve was used to quantitatively determine the percentage of calcite in each sample. As a result, six samples were rejected because their calcite content exceeded 6%. Consequently seven samples were selected for U/Th dating (Table 1.1).

Table 1.1. Results of Th/U dating on seven coral samples from Rogers Wreck Point, Grand Cayman. Depth is measured down from sea-level.

Well I.D.	Depth to sea-level (m)	Coral I.D.	Calcite (weight %)	Age (yrs BP)	Error (yrs) /Comments
RWP#3	4.01	*Acropora palmata*	0.0	232,000	+6,000/-5,000
RWP#6A	5.49	*Porites astreoides*	5.5	346,000	+12,000/-11,000
RWP#10	13.11	*Acropora palmàta*	0.0	>400,000	Some leaching of U
RWP#13	8.23	*Acropora palmata*	0.0	226,000	±7,000
RWP#14	1.88	*Siderastrea siderea*	1.8	129,000	±6,600
RWP#14	17.25	*Acropora palmata*	4.3	>400,000	Possible U leaching
RWP#15	5.38	*Siderastrea siderea*	2.3	133,944	±1,590

1.6.4 Thin Section Petrography

Thin sections were used to identify grains and textures that could not be identified at a macroscopic scale. Determination of skeletal types was made by comparing them to thin sections of known skeletal material and published descriptions (Bathurst, 1975; Scholle, 1978). A total of forty-seven thin sections was examined. Four thin sections from near the contact between the Ironshore Formation (limestone) and the Cayman Formation (dolomite) were stained with Alizarin red s in order to distinguish between calcite/aragonite and dolomite.

CHAPTER II:

STRATIGRAPHY OF THE IRONSHORE FORMATION AT ROGERS WRECK POINT

2.1 Introduction

Previous studies of the Pleistocene strata on the Cayman Islands suggested a simple stratigraphy due to the fact that deposition of the Ironshore Formation took place ~130 ka BP. Evidence for deposition during the last interglacial highstand came from radiometric dates. Brunt *et al.* (1973), Emery (1981), and Woodroffe *et al.* (1983) collected samples from surface exposures of the Ironshore Formation in order to determine the absolute age of the unit. Brunt *et al.* (1973) obtained a radiocarbon age of >40 ka BP on two mollusk shells, *Codakia orbicularis*. This age is beyond the range of the method, indicating that the Ironshore Formation was at least older than Holocene. Emery (1981) also dated mollusk shells (*Strombus*) and one coral (*Diploria strigosa*) from coastal locations on the west side of the island (Figure 2.1). He used the $^{230}Th/^{234}U$ method and obtained an age of 240 ka ± 3 ka BP from one *Strombus* shell and 155 ka ± 10 ka BP from the coral sample. Both dates were presumed to be too old because $^{231}Pa/^{235}U$ ratios indicated low uranium concentrations that were attributed to losses during weathering. Emery (1981) provided no other discussion on the results from the other two conch samples. Woodroffe *et al.* (1983) also used $^{230}Th/^{234}U$ and obtained dates on four corals from surface exposures (three from Cayman Brac, one from Grand Cayman; Figure 2.1). These samples yielded ages of 121 ka ± 6 ka (*Montastrea annularis*), 124 ka ± 6 ka (*Porites astreoides*), 118 ka ± 9 ka (*M. annularis*), and 134 ka ± 9 ka (*M. annularis*), for an average age of 124 ka ± 8 ka BP (Table 2.1). Although Emery 's (1981) and Brunt *et*

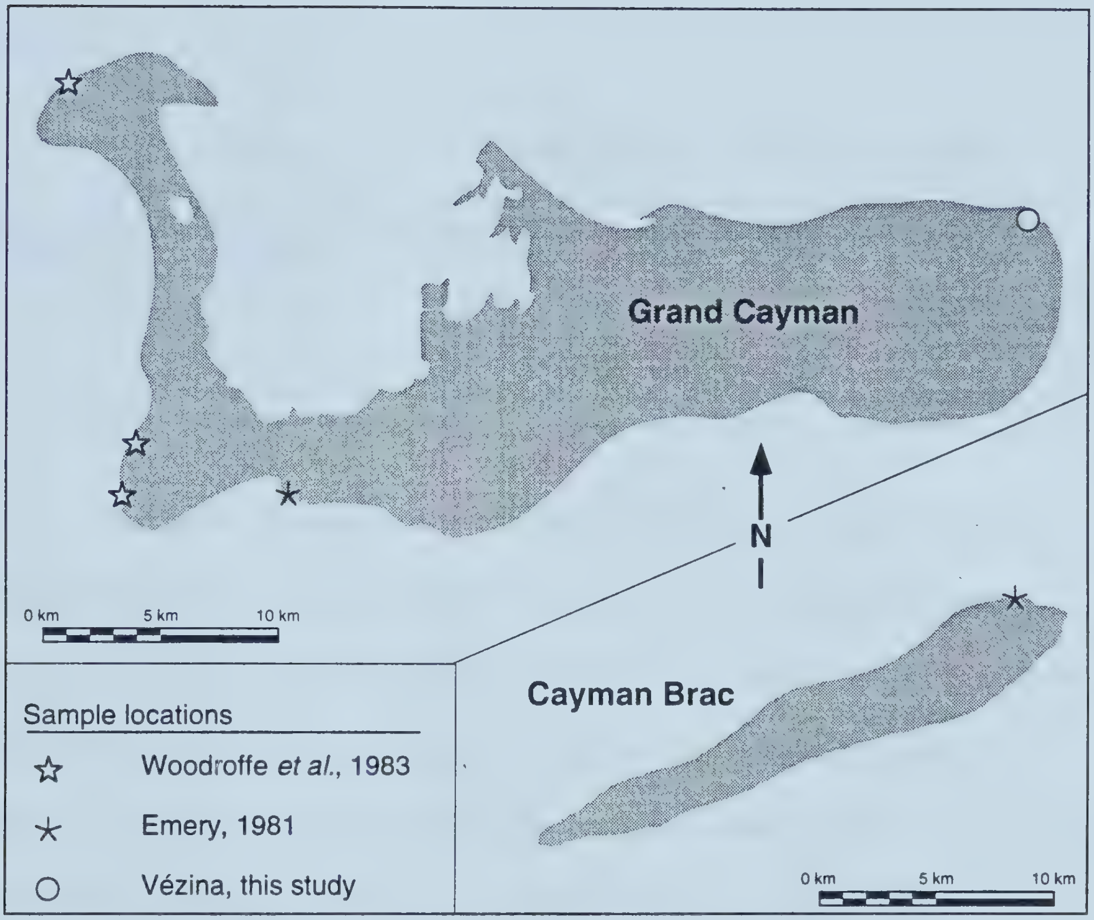


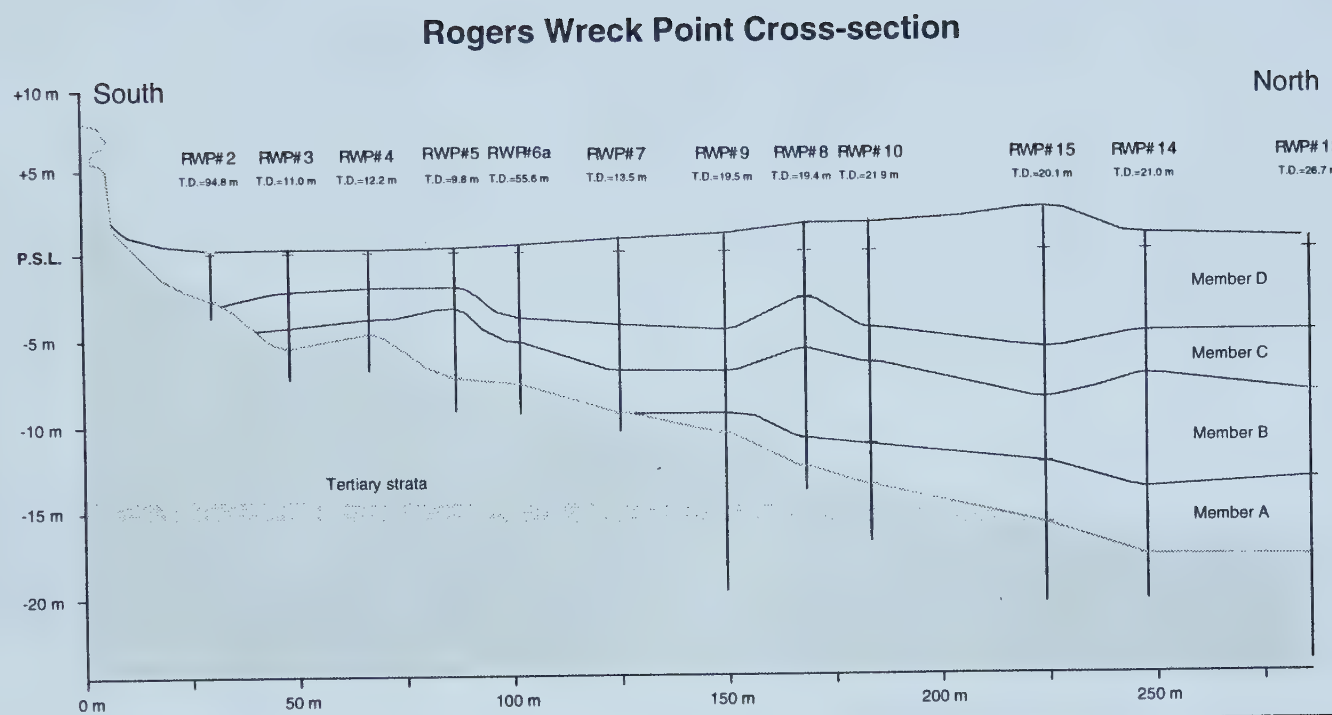
Figure 2.1. Schematic map of sample locations used for dating the Pleistocene Ironshore Formation, Cayman Islands. Samples for this study were taken from the subsurface.

al.'s (1973) results were inconclusive, Woodroffe *et al.*'s (1983) samples indicated the Ironshore Formation was deposited during the last interglacial, the Sangamon Highstand (Table 2.1).

Table 2.1. Summary of results of Th/U dates obtained by Woodroffe *et al.* (1983).

Location	Species	Calcite	Age (ka BP)
Prospect Point, Grand Cayman	*Montastrea annularis*	7 %	121 ± 6
Booby Point, Cayman Brac	*Porites astreoides*	2 %	124 ± 6
Booby Point, Cayman Brac	*Montastrea annularis*	4 %	118 ± 9
Booby Point, Cayman Brac	*Montastrea annularis*	1 %	134 ± 9

New information, however, obtained from the University of Alberta's drilling program on Grand Cayman shows that the depositional history of the Pleistocene succession is more complex than previously outlined. Core recovered from the Rogers Wreck Point area reveals caliches and/or *terra rossa* zones at several levels in the succession. Prior to this study intra-formational disconformities had not been detected in the Ironshore Formation. This is probably attributable to the typically poor core recovery from this formation and limited vertical exposures of the succession on the west coast of Grand Cayman (Jones, 1994). The wells drilled at Rogers Wreck Point, however, with an average core recovery of 52%, allowed identification of the distinct caliche and/or *terra rossa* zones that delineate the disconformities in the Ironshore Formation (Table 2.2). Lateral correlation of these disconformities allowed the delineation of four unconformity-bound units (Figures 2.2, 2.3).



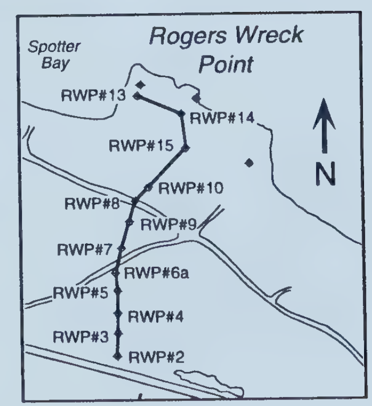


Figure 2.2. Cross-section illustrating the stratigraphic relationships of the four members of the Ironshore Formation at Rogers Wreck Point.

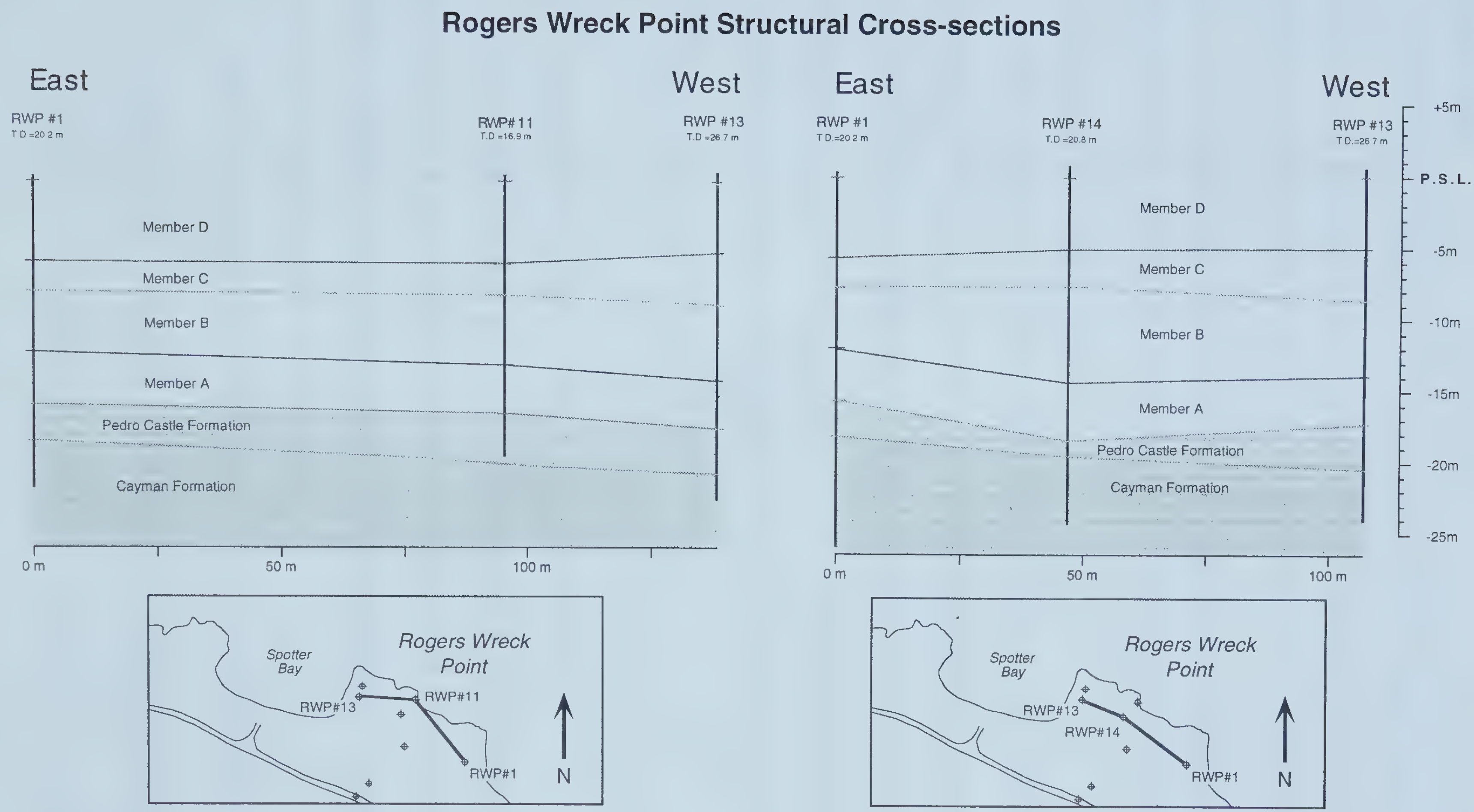


Figure 2.3 Cross-sections illustrating the stratigraphic relationships of the four members of the Ironshore Formation at Rogers Wreck Point.

2.2 Etymology

The Ironshore Formation is bounded above and below by unconformities: above by the present-day exposure surface or mangrove swamp deposits (Woodroffe, 1981) and below by the unconformity developed on the Bluff Group (Jones 1994, 1995). The new units are defined primarily on their bounding discontinuities, the locations of which are supported by radiometric dates. They are therefore best described by a combination of allostratigraphy and lithostratigraphy.

With the data that are presently available, the new units are not mappable across Grand Cayman. They are, however, traceable in the subsurface for 250 m at Rogers Wreck Point. For these reasons the new stratigraphic units are treated as members with the understanding that further mapping may lead to their elevation to formations. Accordingly, from oldest to youngest (bottom to top) the new units are herein designated as Members A, B, C, and D (Figures 2.2, 2.3).

2.2.1 Criteria for Recognition of Units at Rogers Wreck Point

Delineation of the members is based on the positions of the disconformities that are denoted by caliche and/or strong concentrations of *terra rossa*, radiometric dates, subtle changes in lithologic and diagenetic characteristics, and fossil content. All criteria are used because of core recovery problems (Table 2.2)

Table 2.2. Maximum, minimum, and average core recovery for the wells at Rogers Wreck Point, Grand Cayman.

Core Recovery:	Member A	Member B	Member C	Member D
Maximum	100%	86%	96%	79%
Minimum	0%	19%	14%	11%
Average	50 %	45%	61%	52%

1. Caliches

The presence of caliche in the cores provided the clearest evidence for locating the bounding disconformities. Caliches in this succession are typically 2-3 cm thick. Most well-developed examples appear to have formed around large (perhaps up to 5 cm) roots which have since rotted away (Figure 2.4). Fabrics observed in thin section and core included coated grains (Figure 2.5), laminae (Figure 2.6), and numerous rhizoliths (Figure 2.7).

2. *Terra Rossa*

Terra rossa is present in the matrix between corals with dense skeletons, and filling the voids in corals with very open, porous skeletons such as *Diploria* sp. (Figure 2.8a). This 'red earth' was also found in partially-filled borings that had white-to-buff wackestones and mudstones in the base of the cavities (Figure 2.8b).

3. Radiometric Dates

Seven $^{230}Th/^{234}U$ dates obtained from corals support the hypothesis that there are four distinct units (~131 ka BP, ~229 ka BP, ~346 ka BP, and >400 ka BP) at Rogers Wreck Point. The stratigraphic position of these dates (Figure 2.9), integrated with the position of the caliches and *terra rossa* zones, substantiates the placement of the disconformities.

4. Lithological and Diagenetic Changes

The four members of the Ironshore Formation are formed of limestone. Subtle lithological changes, when present, were used to define the boundaries between the units where caliche/*terra rossa* was absent. The most practical lithological changes were colour differences, recrystallization textures, and the amount of leaching. A grey-blue

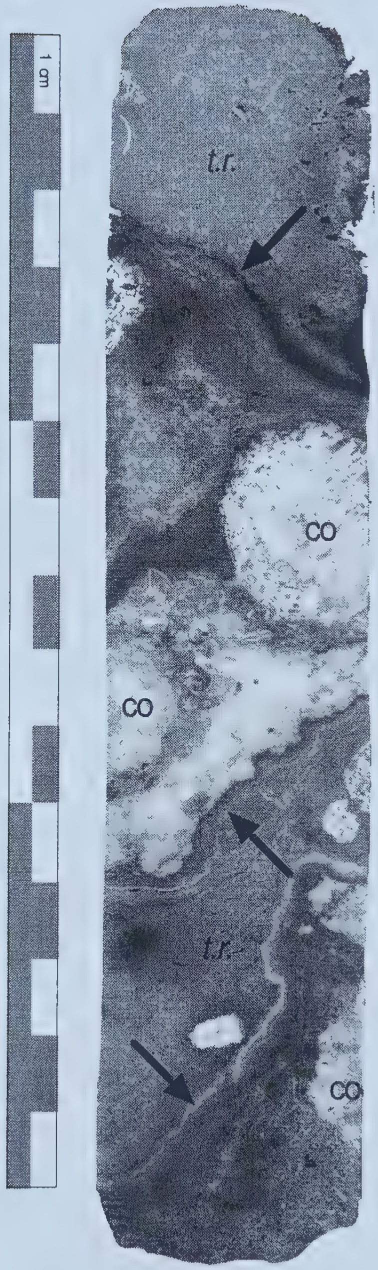


Figure 2.4. Core photo of laminations (arrows) lining a root cast filled with *terra rossa* (*t.r.*). Roots preferentially avoided coral fragments (co) (RWP #14 at 6.1 metres).

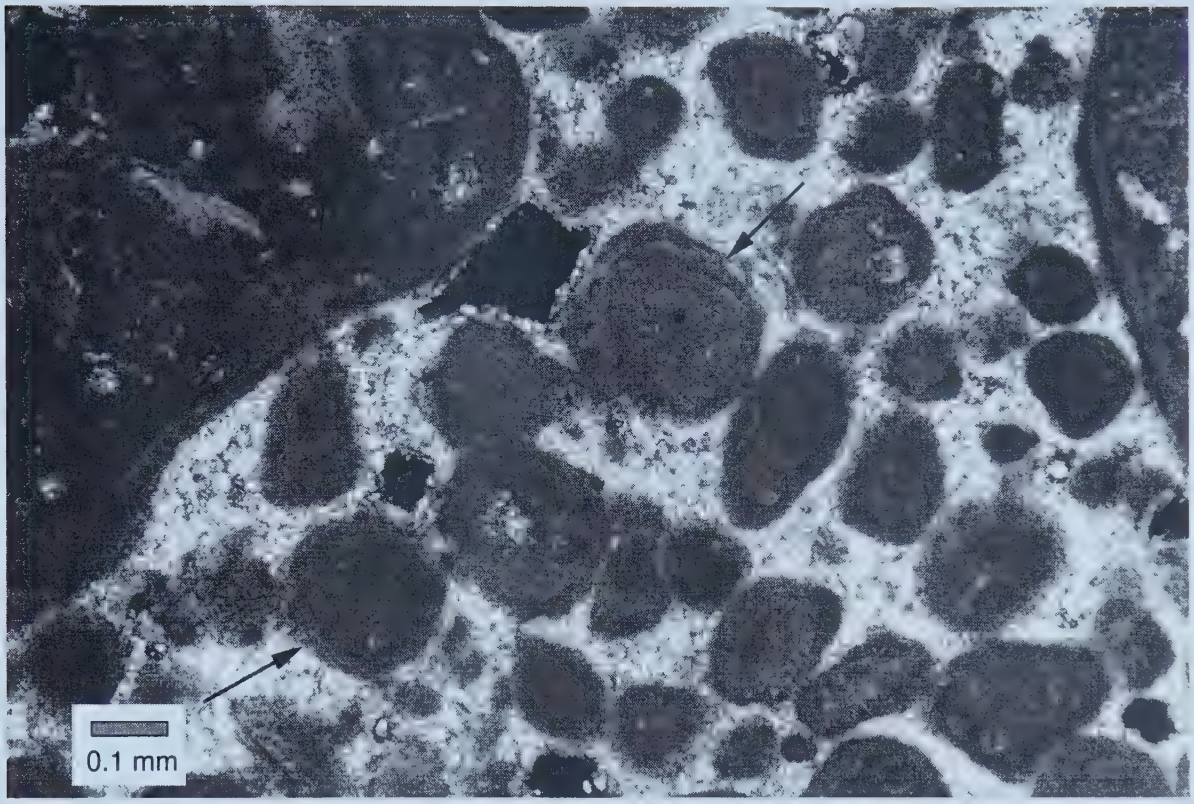


Figure 2.5. Thin section photomicrograph showing coated grains in a meteoric sparry calcite cement filling rhizoliths at a discontinuity, Ironshore Formation, Member B, RWP #3 at 4.9 m.

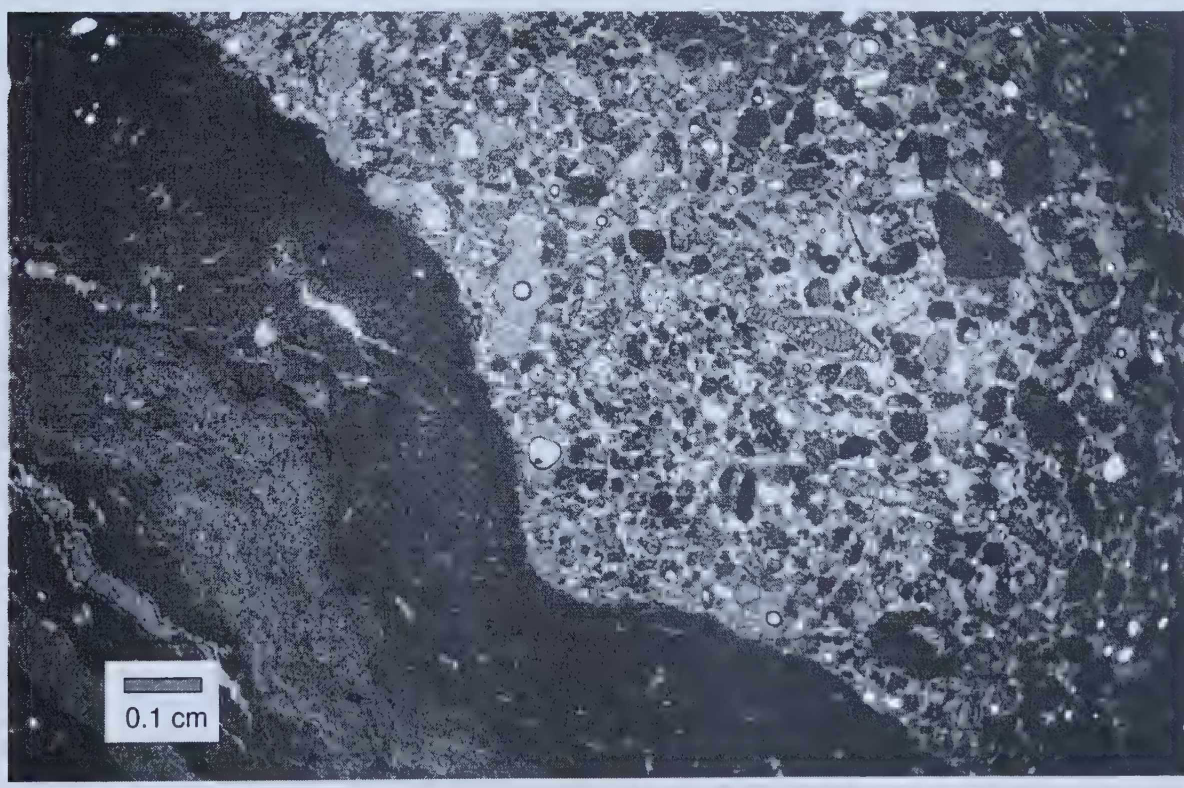


Figure 2.6. Thin section photomicrograph of caliche laminations overlain by a well cemented grainstone, Ironshore Formation, Member D, RWP #7 at 5.0 m.

A

B

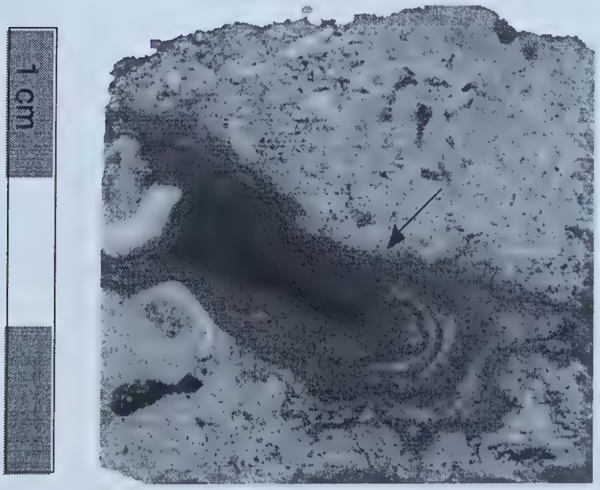


Figure 2.7. A) Core photo of *Halimeda* rudstone with abundant small holes where rootlets (some examples arrowed) have penetrated the rock (RWP #6 at 4.9 metres). B) Core photo of a larger, well-laminated rhizolith (arrow) (RWP #8 at 0.3 metres).

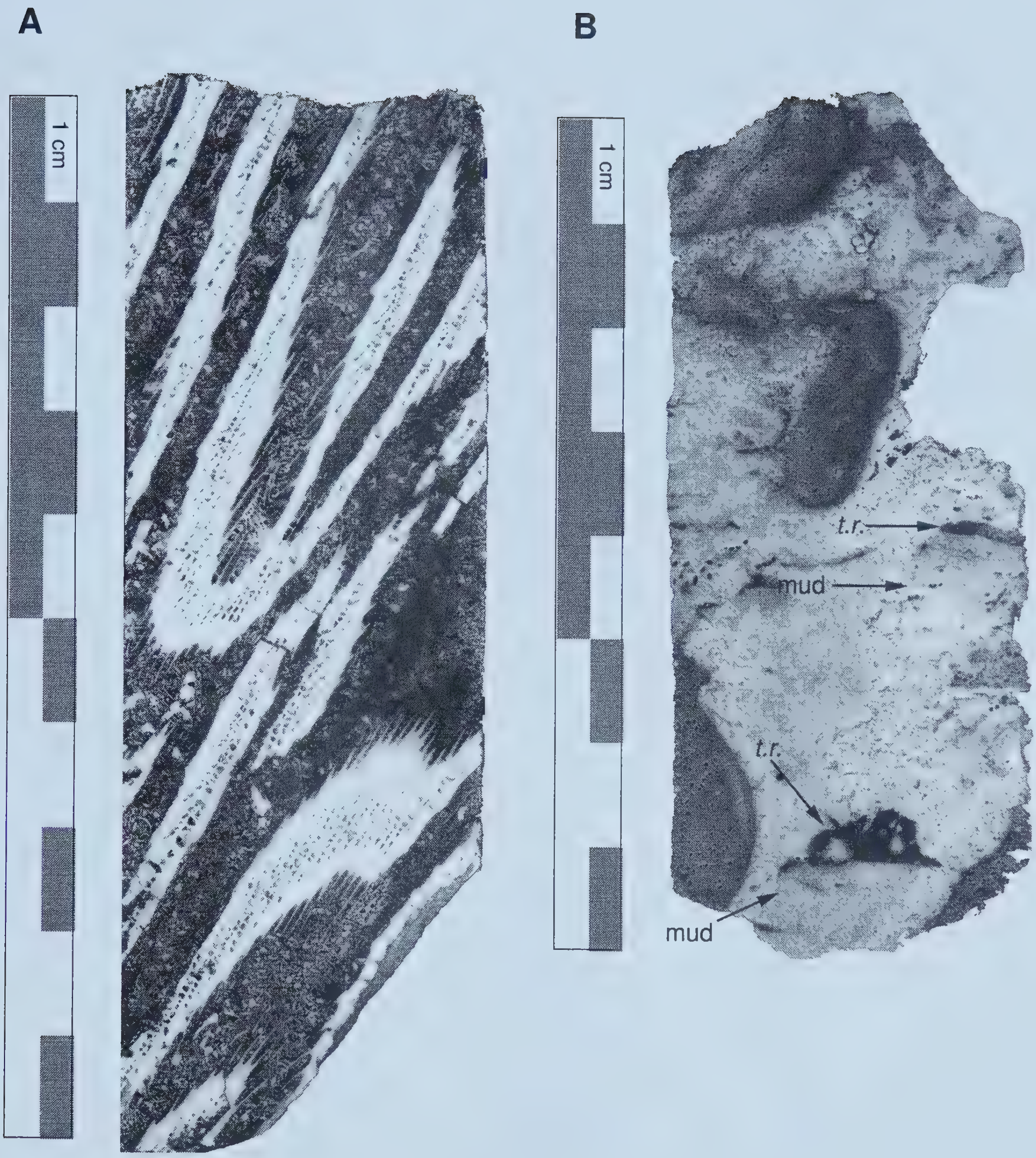
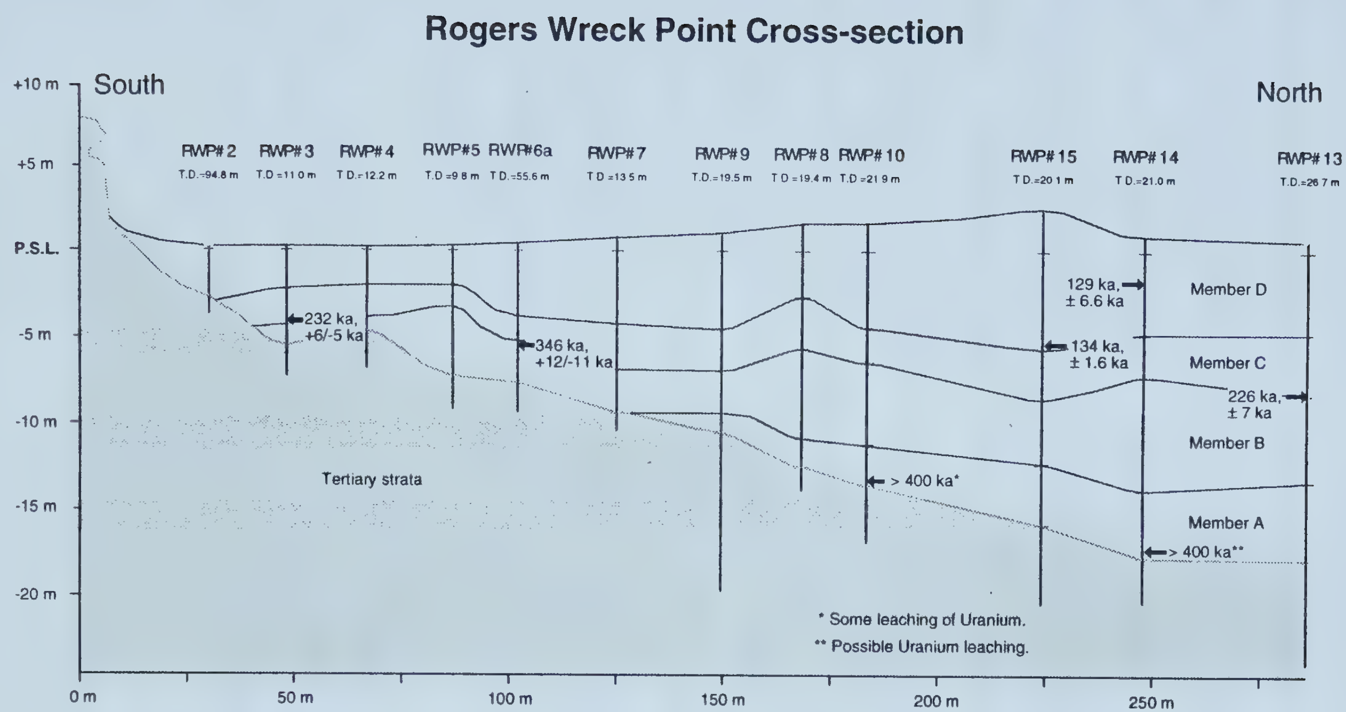


Figure 2.8. A) Core photo of *Diploria* sp. with an open framework filled with *terra rossa* (RWP #1 at 7.6 metres). B) Core photo of borings in a coral partially filled with mud and topped with *terra rossa* (*t.r.*) (RWP #1 at 6.4 metres).



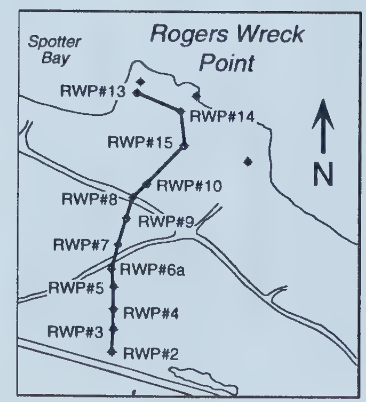


Figure 2.10. Cross-section illustrating the ages and relationships of the four members of the Ironshore Formation at Rogers Wreck Point.

discolouration of the core is an obvious diagenetic feature, and may be genetically associated with the exposure surfaces because it is generally located just above or below the disconformities. This feature is especially common between Members C and D. Aragonite-to-calcite inversion is most obvious in coral species with open skeletal frameworks, such as *Montastrea* sp. and *Diploria* sp. The more open structure of these head corals allowed fluids to be transmitted more easily, and thus permited dissolution and/or recrystallization. Branching corals may be partially to completely leached, but leaching in hemispherical corals is patchy. In general the extent of recrystallization decreases upwards through the sequence. Most open-framework corals in Member A, for example, have undergone complete inversion to calcite, whereas the same coral species in Member D are mostly pristine. The amount of leaching follows the same trend: very few allochems are leached in Member D, whereas moldic porosity can be common in Member A. Of the non-framework material, the shelly grains (gastropods and pelecypods) and *Halimeda* plates are most commonly leached; leaching in unit D is primarily limited to these allochems.

5. Fossil Content

Members B and C can be separated according to the dominant coral morpho-type: Member B contains numerous head corals, whereas Member C contains numerous branching corals. This method is useful where the head coral-dominated facies in one unit overlies a branching coral facies in the other, but is limited in wells where a sandy facies is present in both members.

2.3 Depositional Framework of the Ironshore Formation on the North-East Coast of Grand Cayman

At Rogers Wreck Point the Ironshore Formation was deposited in a coastal setting on a wave-cut platform of Tertiary strata. These strata (the Cayman and Pedro Castle formations) had undergone modification prior to the deposition of the Ironshore Formation (Figure 2.10). This is a stark contrast to the quiet-water, lagoonal setting (Hunter and Jones, 1988 and Jones and Hunter, 1990) in which the sediments of the Ironshore Formation accumulated on the west side of Grand Cayman.

The architecture of the Tertiary surface influenced the deposition of the Pleistocene units. The unconformity on the Tertiary strata initially developed during the Messinian lowstand, and has since been modified by successive periods of exposure (Jones and Hunter, 1994). The rugged, uneven topography on this unconformity, which has a relief of up to 50 m, is the product of karst erosion (Jones and Hunter, 1994). At Rogers Wreck Point, however, the karst landscape was modified by coastal erosion. Marine planation in this coastal setting has resulted in a relatively smooth topography (Figure 2.10).

The result of this marine planation has been a surface of near constant gradient which slopes downward at ~3° to the north (seaward). Changes in the gradient of the Tertiary platform vary from minor breaks in slope to near-vertical cliffs. These variations in gradient occur in the southern part of the section, where the cliffline is the most conspicuous feature. An erosional notch is cut into these cliffs at ~+6 m above present sea-level. Hunter and Jones (1988) proposed that the notch was cut by a sea-level stillstand during the Sangamon Highstand approximately 130 ka BP. The cliffs, then, must have existed prior to this. There is no indication that other wave-cut notches

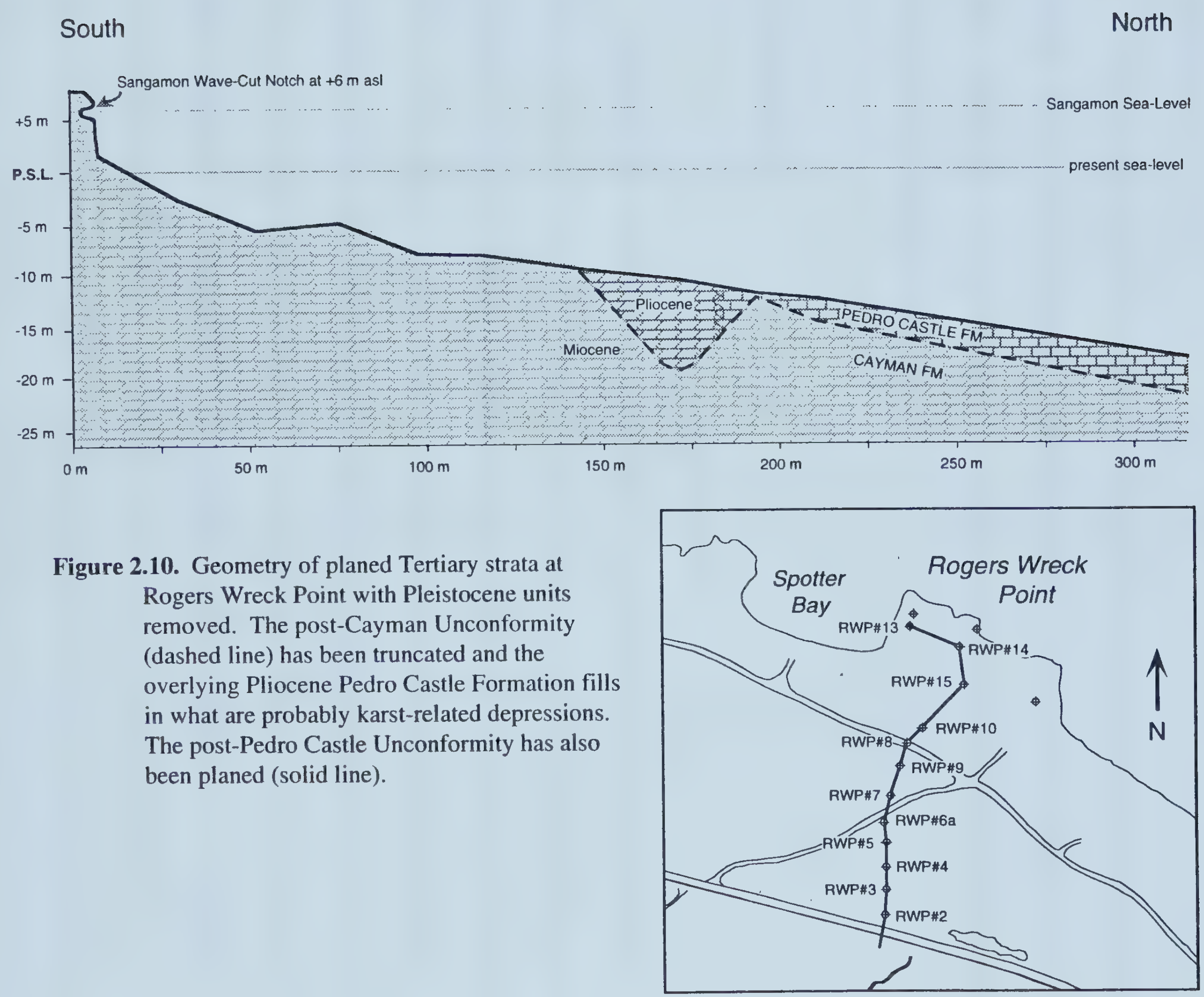


Figure 2.10. Geometry of planed Tertiary strata at Rogers Wreck Point with Pleistocene units removed. The post-Cayman Unconformity (dashed line) has been truncated and the overlying Pliocene Pedro Castle Formation fills in what are probably karst-related depressions. The post-Pedro Castle Unconformity has also been planed (solid line).

associated with deposition of the older units exist. Considering the cyclic nature of these depositional events, the absence of wave-cut notches associated with Members A, B, and C is potentially an indication that sea-level was not as high for these three units as it was ~130 ka BP.

The successive deposition of four Pleistocene units, each separated by an exposure surface, suggests a cyclic control on their deposition. The control mechanism is the eustatic change in sea-level. Deposition took place on the shelf during highstands, and soils developed during lowstands.

2.4 Member A

Boundaries

Member A unconformably onlaps the Pedro Castle Formation and pinches out between RWP#7 and RWP#9 (Figure 2.11). Member A of the Ironshore Formation and the Pedro Castle Formation contain similar corals (*e.g., Porites*), textures, and colours. In RWP#9, however, the Pedro Castle Formation is dolomitized, whereas Member A contains no dolomite. In this case, the units can be identified according to mineralogy. In other wells (RWP#10, #15, #14, and #11), however, the Pedro Castle Formation is entirely limestone. Characteristics of the Pedro Castle Formation that were used to differentiate it from Member A include (1) an increase in the density and the recrystallization of the core, (2) abundant *Entobia* in the molds of leached branching corals, and (3) a dark rust-coloured stain on the outside of the core and on the surfaces of the cavities created by the dissolution of skeletal allochems. Furthermore, the presence of the coral *Acropora palmata* in Member A confirms this unit is Pleistocene in age.

Ironshore Formation, Member A Cross-section

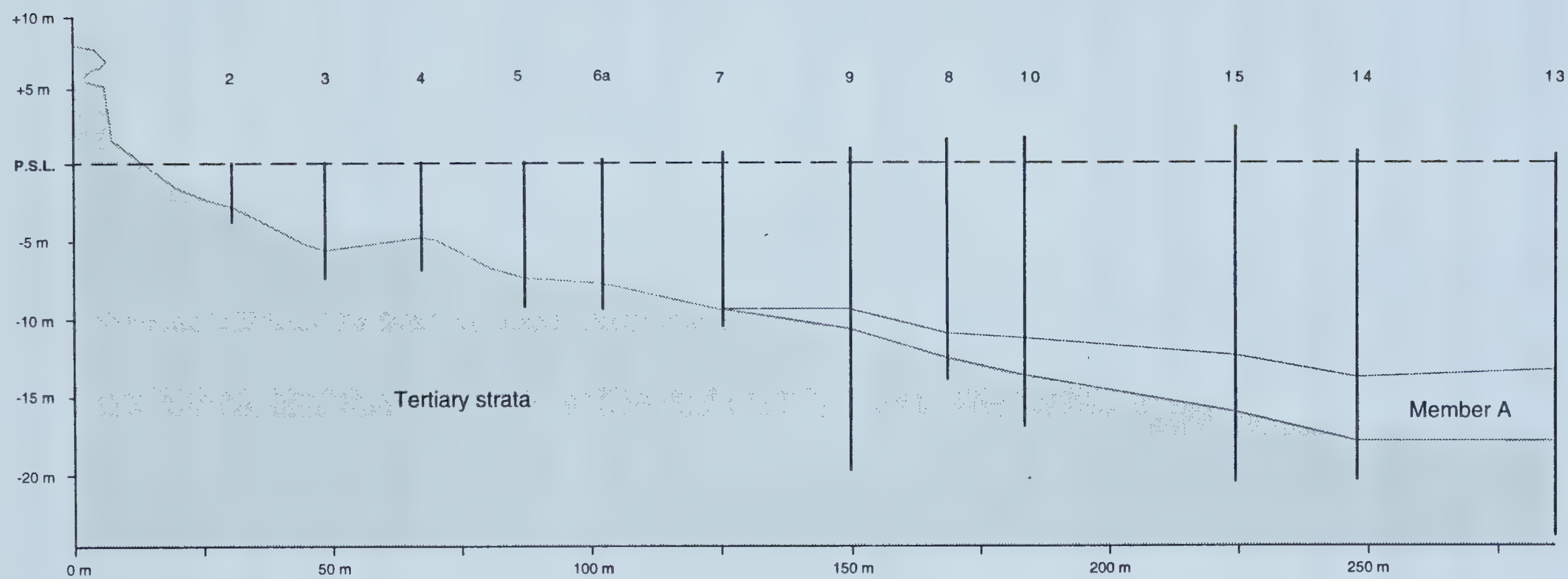


Figure 2.11. Cross-section illustrating the position of Member A of the Ironshore Formation at Rogers Wreck Point.

Although Pleistocene and Pliocene strata share some biota, *Acropora palmata* is found only in strata of Pleistocene age or younger (Frost, 1977).

The disconformity separating Member A from the overlying Member B is commonly poorly defined. Core recovery is typically poor just above and below the contact. The contact was chosen based on the diagenetic character of the core: Member A consistently appeared more recrystallized than Member B. A small amount of *terra rossa* and a few rhizoliths in RWP#12 are the only evidence of subaerial exposure. There is ~4 m of relief on the unconformity, and two slight changes in slope (between wells RWP#14 and #15, and wells RWP#8 and #9).

Thickness

Member A is a wedge-shaped unit that thickens from the south (0 m in RWP#8) to the north (4.09 m in RWP#14) (Figure 2.11).

Age

Two radiometric dates indicate that Member A is >400 ka BP. This age is further constrained to the Pleistocene (<1.7 Ma BP) because Member A contains *Acropora palmata*, a coral which appeared post-Pliocene (Frost, 1977).

Lithology

Member A is dominated by grainstone and framestone, with subordinate amounts of packstone and wackestone. No systematic vertical or horizontal trends were detected in the facies in Member A. The allochems are fine-grained and moderately to highly abraded, indicating that hydraulic abrasion was an important process during their deposition. Many grains are highly micritized (up to 60% micritized). Identifiable skeletal fragments include foraminifera, *Halimeda* plates, red algae, bivalves, and

gastropods. *Entobia* is common to abundant in molds of branching corals, whereas head corals exhibit bivalve borings that have since been filled to varying degrees with micrite. The bivalve borings are especially abundant in RWP#14.

Member A is formed of dense, well-indurated, white, beige-brown rubbly limestones that have undergone patchy recrystallization from aragonite to calcite. Recrystallization has obliterated original textures. Leaching preferentially affected the branching corals, gastropods (original mineralogy is aragonite), and *Halimeda* fragments. Leaching of some grainstones created an unusual "spongy" texture by dissolving the allochems but leaving the clear circumgranular and intergranular cements (Figure 2.12).

Biota

Corals include *Acropora palmata*, *Diploria strigosa*, *Porites* sp., *Montastrea annularis*, and *Siderastrea* sp. (?). All the corals are extensively bored (*Trypanites* and *Entobia*) and encrusted by up to 2-3 cm of red algae and forams.

2.5 Member B

Boundaries

Member B onlaps the unconformity with Member A, and the post-Pedro Castle Formation unconformity (Figure 2.13). The lower boundary of Member B has a near-constant gradient (~6°), except for a break in slope between wells RWP#4 and RWP#5. The apparent dip of the break in slope is ~20° down to the north.

The upper boundary of Member B is an unconformity with Member C. Relief on this unconformity is ~5 m. The boundary is defined by *terra rossa*, which is common in the south but conspicuously absent in the north (RWP#9, #8, #10, #15, and #14; some

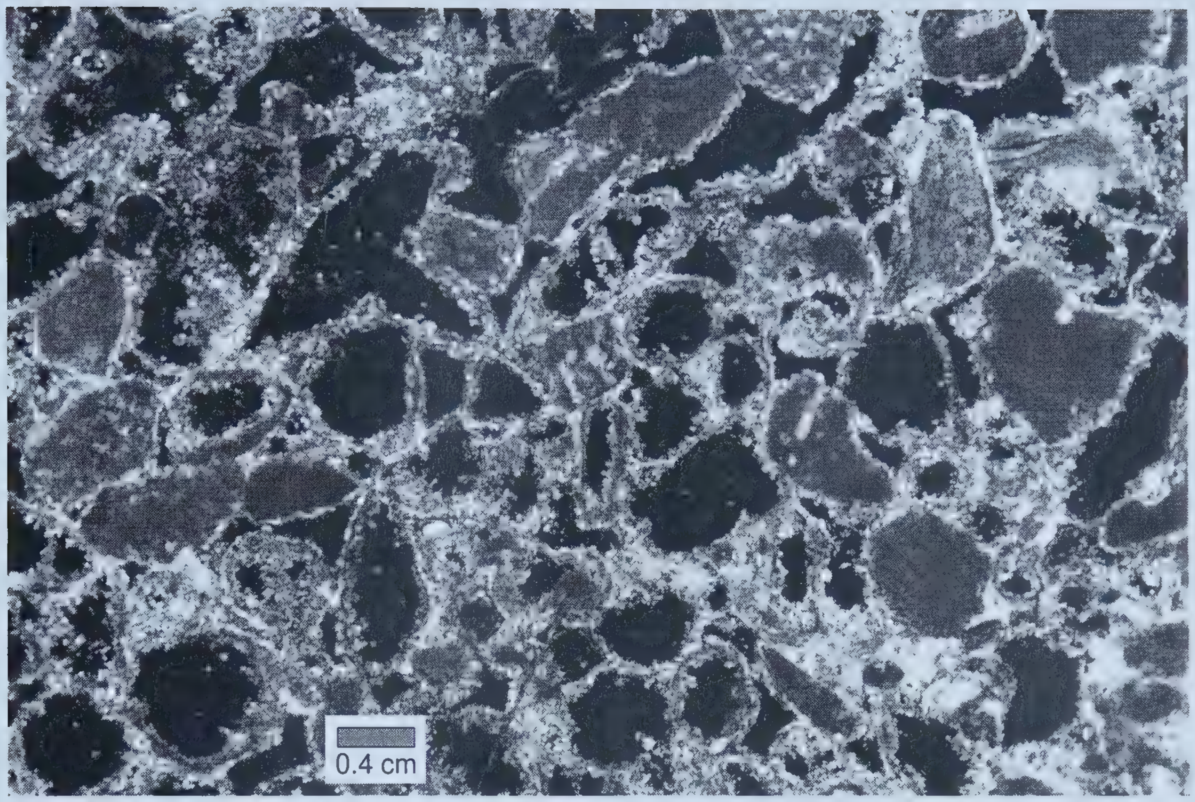


Figure 2.12. Thin section photomicrograph of a 'spongy' textured grainstone. The allochems in this grainstone are leached, leaving the circumgranular crust cements and porosity (black), Ironshore Formation, Member D, RWP #10 at 13.3 m.

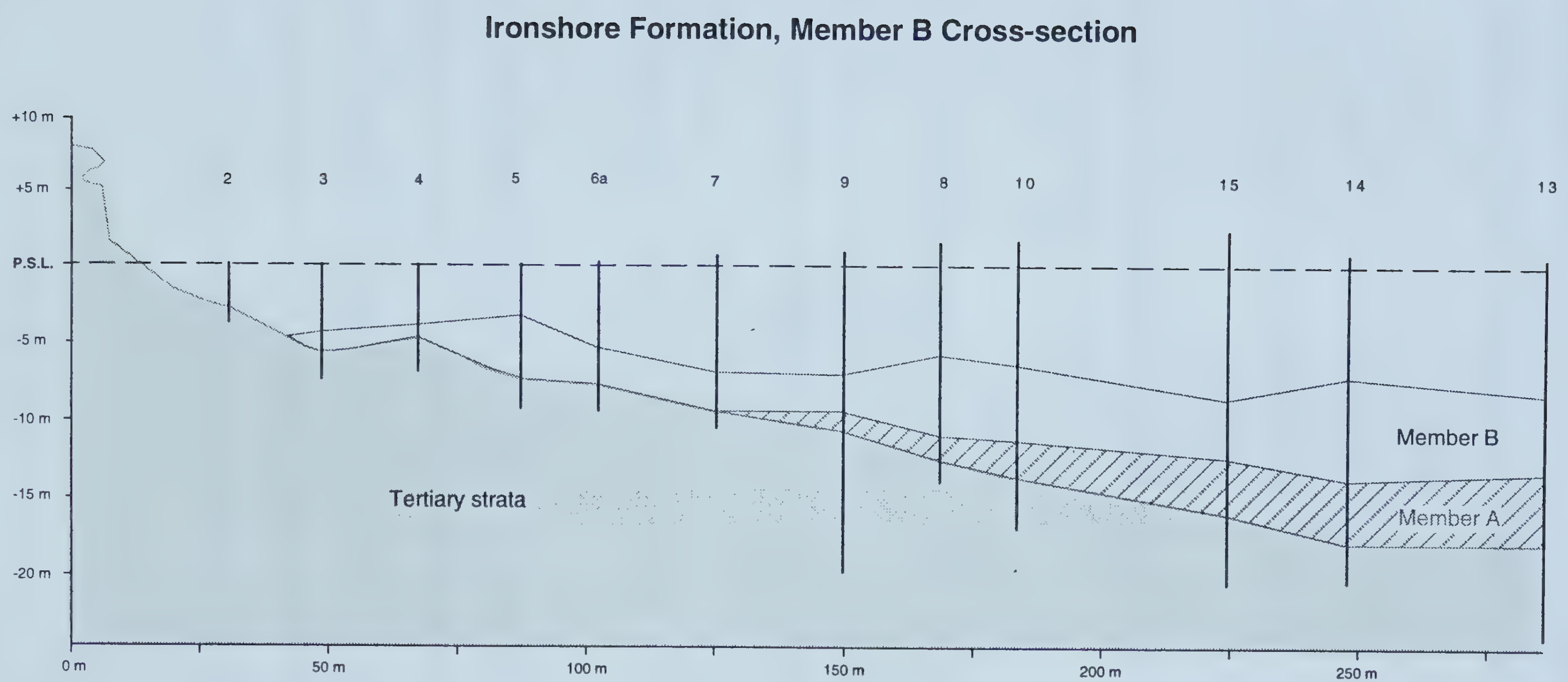


Figure 2.13. Cross-section illustrating the position of Member B of the Ironshore Formation at Rogers Wreck Point.

terra rossa is present in RWP#11 and #1). In the north the contact is placed between the numerous head corals in Member B and the numerous branching corals in Member C.

Thickness

Member B is absent in RWP#2 and thickens to the north, attaining a maximum thickness of ~6.7 m in RWP#14; the average thickness is ~3.7 m.

Age

The single radiometric date obtained for Member B (RWP#6a at 5.49 m) indicates that it was deposited ~346 ka +12/-11 ka BP.

Lithology

Member B is composed of packstones, grainstones, and minor wackestones; grainstones are rare to the south. Framestones and rudstones, which are common in the northern part of the area (north of RWP#7), have matrices of mudstones to grainstones. The colour of the core is controlled by the amount of mud and *terra rossa* present; the more mud, the whiter the core, the greater the amount of *terra rossa*, the more rust-coloured the rock.

Muddier portions of the core tend to be better indurated, whereas poorly-cemented sandier sections tend to be rubbly. The degree of induration of the core varies in direct relation to texture and presence or absence of *terra rossa*: sands become more well-indurated, whereas sections with abundant coral fragments (coarse grainstones to rudstones) tend to be rubbly. It appears that the degree of induration increases to the north.

Member B is mostly still aragonite. Recrystallization to calcite is patchy both within and between wells. In general, Member b in the northern section appears to have undergone a greater degree of recrystallization than Member B in the southern wells.

Biota

Member B is dominated by head corals in the northern part of the area. As in Member A, most corals are extensively encrusted by thick layers of red algae (up to 3 cm thick) and bored by bivalves, serpulids, and sponges. Skeletal components include foraminifera, *Halimeda* plates, *Homotrema*, red algae, echinoid spines, bivalves, and gastropods. Corals in Member B include *Montastrea annularis*, *Porites astreoides*, *Porites porites*, *Dichocenia stokesii* (?), *Siderastrea* sp., *Diploria strigosa*, *D. clivosa*, *Diploria* sp., *Acropora cervicornis* (?), *Goniapora* (?), and *Acropora* sp. The most abundant coral is *Montastrea annularis*.

2.6 Member C

Boundaries

Member C is separated by an unconformity from Member B and by an unconformity from the Tertiary Cayman Formation (Figure 2.14). The boundary between Member B and Member C has been described above.

The upper contact of Member C, which has ~3 m of relief, mimics the relief on the upper contact of Member B. The contact between Member C and Member D is identified in most wells by *terra rossa* and rhizoliths in the core. These criteria are especially useful in the southern part of the area, where the facies between Member C and Member D are similar. The boundary between Member C and Member D is recognized

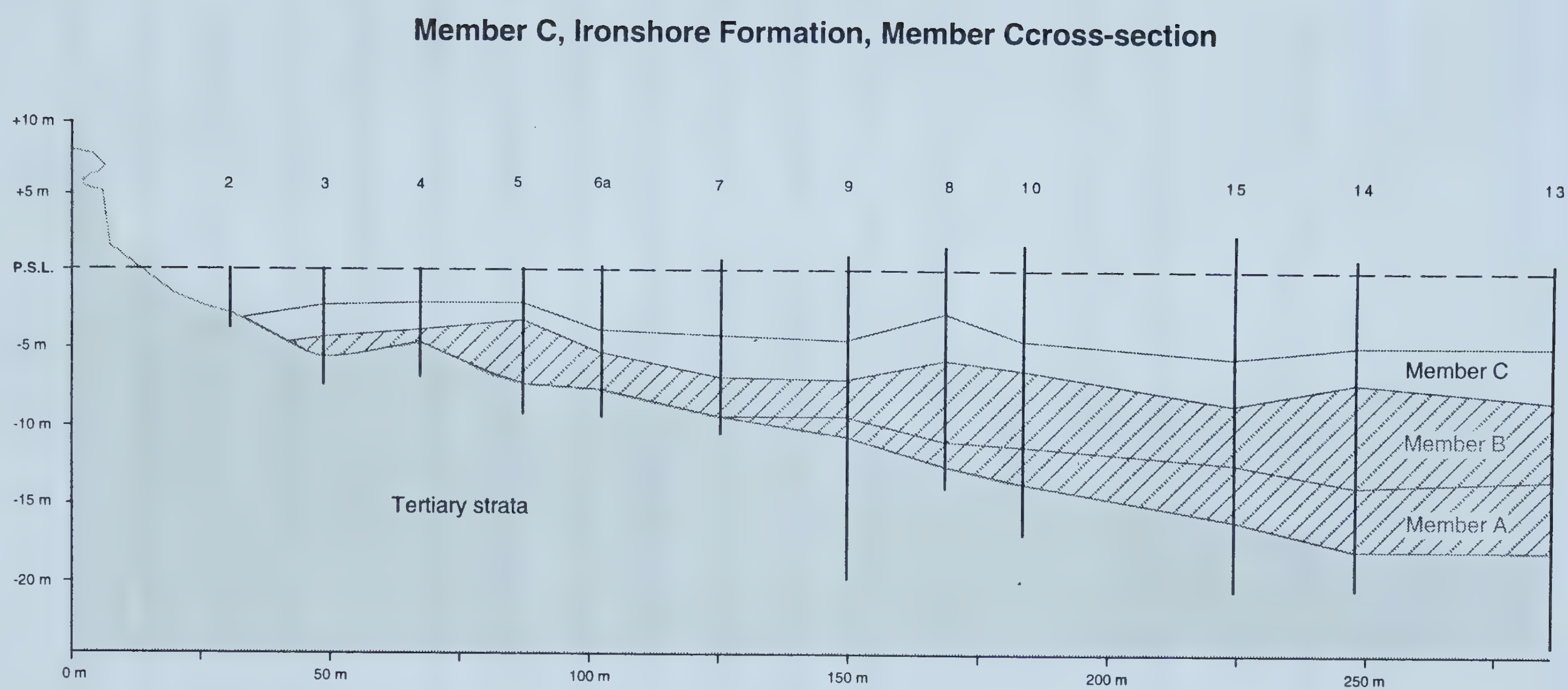


Figure 2.14. Cross-section illustrating the position of Member C of the Ironshore Formation at Rogers Wreck Point.

in the north by the numerous branching corals in Member C and the numerous head corals and sands at the base of Member D.

Thickness

Member C has an average thickness of ~2.3 m and a maximum thickness of 3.6 m in RWP#13. There is little variation in the thickness of the unit across the study area.

Age

Two radiometric dates were obtained from this unit: 232 ka +6/ -5 ka BP from RWP#3 and 226 ka ±7 ka BP from RWP#13.

Lithology

Buff to white rudstones, packstones, grainstones, framestones, and bafflestones characterize Member C. Skeletal sands, which are abundant to the south, contain numerous micritized grains. Framestones and bafflestones are common in the north. In well RWP#11 this member is composed almost entirely of rudstone.

The fine to medium sands are composed of benthic foraminifera, *Halimeda*, coral fragments, red algae, *Carpenteria*, *Homotrema*, echinoid spines, pelecypods, and gastropods. The gastropods, which are locally abundant, are typically small. Highly abraded skeletal components in some grainstones indicate that hydraulic abrasion was a locally important depositional process.

The sequence is well-indurated except in zones that contain *terra rossa* and/or caliche. *Terra rossa* is a minor component in wells RWP#2, #3, #4, #5, and #6a, but is common in most of the other wells, thus imparting a distinctive red-brown colour to the rock. White allochems floating in a red *terra rossa* matrix are common. Rhizoliths are

also common, and impart a yellow to brown discolouration to the rock immediately surrounding them. Some gray-blue discolouration is also associated with caliches.

There is minor, patchy leaching of allochems (predominantly aragonitic shells, such as gastropods and pelecypods; leaching of *Halimeda* is variable) and very little recrystallization in Member C. Leaching of allochems is most common in well-cemented, highly abraded grainstones, thus creating the spongy texture like that found in Member A (*e.g.*, Figure 2.12). Recrystallization is most obvious in zones which have been strongly affected by subaerial exposure, where reactions rinds are present around some coral fragments.

Biota

Branching corals, especially *Acropora cervicornis* and *Porites porites*, are common to the north. The abundance of these two branching corals and the scarcity of head corals characterize Member C. *Acropora palmata* is common as boulders in the northern part of the area. Encrusting red algae and foraminifera up to 3-4 cm thick is common on all corals. Skeletal components are as in Member B.

2.7 Member D

Boundaries

Member D onlaps the Cayman Formation (Figure 2.15). The contact between Pleistocene and Tertiary rocks is exposed in outcrop just below the cliffs of the peripheral ridge on the south side of the Queen's Highway.

The upper boundary of Member D is the present land surface at Rogers Wreck Point. A thin calcareous crust is present on the exposed surface of Member D and imparts a

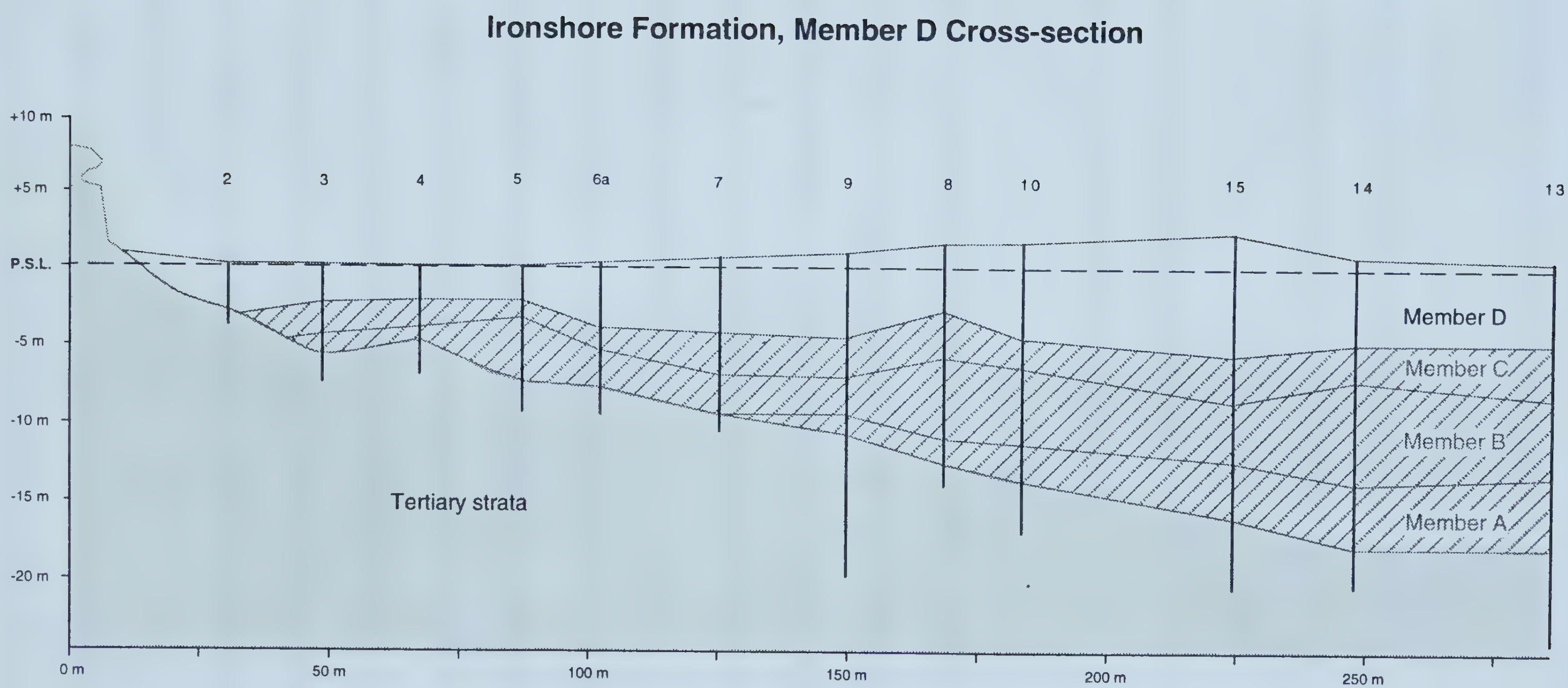


Figure 2.15. Cross-section illustrating the position of Member D of the Ironshore Formation at Rogers Wreck Point.

gray colour to the outcrops. This surface has a subdued relief of <3 m that is less than that associated with members A, B, and C (Figure 1.6).

Thickness

Member D has a maximum thickness of ~5.8 m in RWP#15, and an average thickness of ~4 m. This unit generally thickens to the north.

Age

Two dates from this study constrain Member D's age: 129 ka ±6 ka BP from RWP#14 and 133.9 ka ±1.590 ka BP from RWP#15.

Lithology

Member D is composed of beige-brown grainstones, packstones, rudstones, and framestones, with minor bafflestones, wackestones and mudstones. Grainstones are found throughout the study area, whereas packstones, wackestones, and mudstones are more common to the south. Framestones are found locally in the southern part of the area, but are common to the north.

Skeletal sands are composed of gastropods, pelecypods, red algae, benthic foraminifera, *Homotrema*, *Carpenteria*, *Halimeda*, echinoid spines, coral fragments, serpulid worm tubes, and barnacles. Grain size ranges from very fine to very coarse, and generally decreases to the south. This is the only unit at Rogers Wreck Point where thick (up to 0.5 cm) pelecypod shells are common. Many shells (pelecypods and gastropods) still retain their colours, as do the *Homotrema*. All the allochems are micritized, and well-rounded grains are rare.

The rock takes on a lighter colour with increased amounts of mud, a pink-brown hue where *terra rossa* is present, and is commonly brown at the top of the core where caliche

is present. These altered zones at the top of the core are very well indurated, as are areas with more mud in the matrix. Sandy zones tend to be friable and rubbly where poorly cemented. Framestones vary from crumbly to very-well indurated, depending on whether or not mud is present in the matrix (the more mud, the better the induration).

Allochems are well preserved, many still having their original colour. Minor leaching of aragonitic components (primarily gastropods, and some pelecypods) has taken place in the northern part of the study area. Aside from obscuring of textures by caliches and *terra rossa*, no obvious recrystallization was noted in unit D.

Biota

Corals include *Favia fagrum*, *Diploria* sp., *D. labyrinthiformis*, *D. strigosa*, *Porites* sp., *P. astreoides*, *P. porites*, *Siderastrea* sp., *S. siderea*, *Montastrea annularis*, *Dichocoenia stokesii*, *Acropora* sp., *A. cervicornis*, *A. palmata*, *Goniapora* sp. (?), and *Cylindricus* (?). Additional corals identified in surface exposures of Member D include: *Isophyllastrea rigida*, *Agaricia* sp., *Montastrea cavernosa*, *Diploria clivosa*, *Eusmilia fastigiata*, *Mycetophillia ferox*, and *Manicina areolata*. The apparent greater diversity in coral species in Member D over the other units is, in part, a function of its exposure at surface.

Allochems and corals found in Member D are the same as those in the other three units. The corals are extensively encrusted by red algae and foraminifera (up to 3 cm thick) and bored by sponges and bivalves.

2.8 Synopsis

Four previously unidentified Pleistocene units have been discovered at Rogers Wreck Point, Grand Cayman. The new members of the Ironshore Formation are Member A (>400 ka BP), Member B (~346 ka BP), Member C (~229 ka BP), and Member D (~131 ka BP). All four members are limestone, and still have most of their original aragonitic components. The biotas and textures in each of the members are similar.

Each unit is separated from the overlying unit by an unconformity. *Terra rossa* and/or caliche is/are present on the subaerial exposure surface developed between each member. Th/U dates obtained from corals support the presence of the four units and substantiate the positions of the disconformities. Deposition was controlled by repeated highstands and lowstands of sea-level over the last 400 ka BP.

CHAPTER III:

SEDIMENTOLOGY AND FACIES OF THE IRONSHORE FORMATION AT ROGERS WRECK POINT

3.1 Introduction

The Pleistocene units at Rogers Wreck Point were deposited on a narrow (<650 m), low- to moderate-energy shelf. The location of Rogers Wreck Point on the protected-windward margin of the island means that the prevailing low- to moderate-energy conditions are intermittently interrupted by hurricanes that pass over Grand Cayman from the northeast and southeast (Blanchon, 1995). In modern lagoons on Grand Cayman these storm events are responsible for sediment redistribution, sediment homogenization. and damage to the reefs (Kalbfleisch, 1995).

A full range of facies from mudstones through to framestones is found in the Ironshore Formation at Rogers Wreck Point. Their distribution in the members is used to construct paleodepositional environments for the four time periods represented. Modern, narrow-shelf coastal lagoons on Grand Cayman provide the modern analogs for each member.

3.2 Skeletal Components of the Ironshore Formation at Rogers Wreck Point

The same skeletal components are present in all four members of the Ironshore Formation at Rogers Wreck Point, and vary only in their preservation and condition within and between members. These allochems include *Halimeda* plates, benthic foraminifera (*Archaias angulatus* and *Amphistegina gibbosa* are especially numerous, as are encrusting species such as *Homotrema* sp. and *Carpenteria* sp.), gastropods, bivalves,

ostracodes, worm tubes, echinoid spines, encrusting and coralline red algae, and scattered pelagic foraminifera. Red algae and foraminifera, which are nearly ubiquitous throughout the Ironshore Formation of the study area, encrust all corals (up to 4 cm thick on some corals) and form much of the detrital material. Skeletal framework organisms include numerous branching (*Acropora palmata*, *A. cervicornis*, *Porites porites, Goniapora* sp.(?)) and head corals *(Diploria strigosa, D. clivosa*, *D. labyrinthiformis*, *P. astreoides*, *Montastrea annularis*, *M. cavernosa*, *Siderastrea* sp., very rare *Dichocoenia stokesi*, very rare *Agaricia* sp., *Cylindricus* sp. (?), *Manicina areolata*, *Favia fagrum*, *Mycetophyllia ferox*, *Eusmilia fastigiata*, and *Isophyllastrea rigida).* A few solitary corals were found as well.

Grain characteristics considered to be useful indicators of depositional processes include the degree of (1) bioerosion, (2) micritization, (3) abrasion, (4) articulation, and (5) fragmentation. In general, sponge borings attacked mostly branching corals whereas boring bivalves focused on head corals. Most (~80%) grains in the Ironshore Formation are micritized, with the degree of micritization ranging from micritic envelopes to complete grain micritization. The combination of micritization and abrasion commonly masks the origin of the grains. The number of articulated grains was negligible, although most were fragmented.

The sediments were generally poorly to moderately sorted, with scattered examples of very-well sorted material.

3.3 Facies and Interpretation

The Ironshore Formation at Rogers Wreck Point is formed of the rudstone, grainstone, packstone-wackstone-mudstone, head coral, and the branching coral facies. These five facies are found in each member of the formation, albeit in differing proportions.

Identification of *in situ* biota is important because it aids in the understanding of the processes operating at the time of deposition. Determination of life position of corals in the core was based on an assessment of the (1) geopetal fabrics in borings (Figure 3.1), (2) orientation of the coralites, (3) and position of phototrophic encrusting red algae.

Furthermore, it is assumed that for each unit there is a 'lag time' for the establishment of the carbonate factory following the related transgression (Jones and Desrochers, 1992). Estimates of 1 to 2 m of water (the 'lag depth') are needed before circulation becomes effective enough to allow sediment production, accumulation, and dispersal (Enos, 1977; Harris, 1979; Hardie and Shinn, 1986).

3.3.1 Facies Distribution in Member A

Unit A is characterized by the near-absence of a sytematic trend in its facies: they do not persist very far in either a vertical or lateral sense. Grainstones, packstones, framestones, bafflestones, and rudstones are present in this member (Figure 3.2).

Grainstones are found throughout the study area, whereas packstones are limited to the northern part of the area. Allochems in the grainstones are typically well-rounded and polished, suggesting high levels of hydraulic abrasion. Grainstones composed of highly abraded medium to coarse sand sizes are typically well-sorted. Circumgranular, calcite

Figure 3.1. Thin section photomicrograph of different geopetal fabrics (arrows) showing different orientations by successive displacements of the boulder, Ironshore Formation, Member C, RWP #11 at 6.9 m.

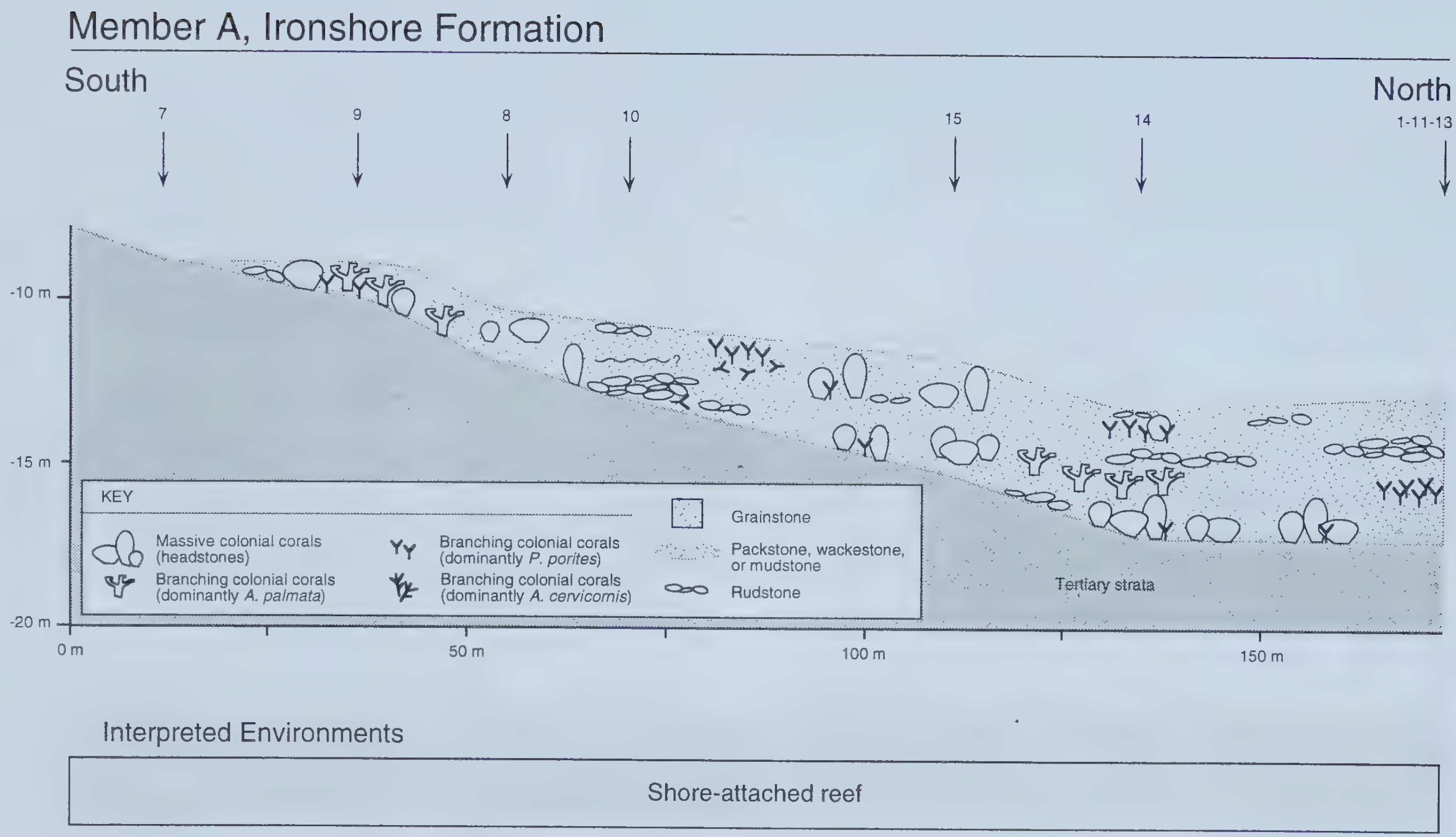


Figure 3.2. Schematic cross-section of the facies distribution in Member A of the Ironshore Formation, Rogers Wreck Point (numbered arrows indicate well locations).

mosaic cements are evident in some of these. In core there were no obvious primary sedimentary structures, but thin sections of the packstones reveal 'pods' (on the scale of a few centimetres at most) of grainstone. Deposit feeding behaviour or simple locomotion through the sediments by infaunal organisms are the most likely causes of this texture.

Branching and head corals in life position are present throughout the study area. The branching corals have been strongly attacked by sponges (*Entobia*) and the head corals by boring bivalves (*Lithophaga*). The borings commonly contain mudstone, wackestone, or more rarely, fine-grained packstones, thereby forming geopetal fabrics.

Evidence of a hardground is found only in RWP#10. The truncated grains of a packstone are overlain by a grainstone (Figure 3.3), strongly suggesting a depositional hiatus. There is, however, little relief on the contact (<3 cm) which is located at ~13.3 m below present sea-level.

The variable preservation of skeletal and non-skeletal material is probably controlled primarily by original mineralogy. Pelecypods may be partly leached, whereas gastropod tests and *Halimeda* plates are totally dissolved. In many of the well-cemented grainstones most of the components are leached, leaving behind the circumgranular crusts and micrite envelopes. These grainstones are typically well-sorted and have a distinctive appearance in core that resembles a 'spongy' texture (Figure 2.12).

Only one well, RWP#11, shows any sign of calcrete development at the upper surface of Member A: some dissolution cavities or root holes are lined with 1-2 mm of brown laminations.

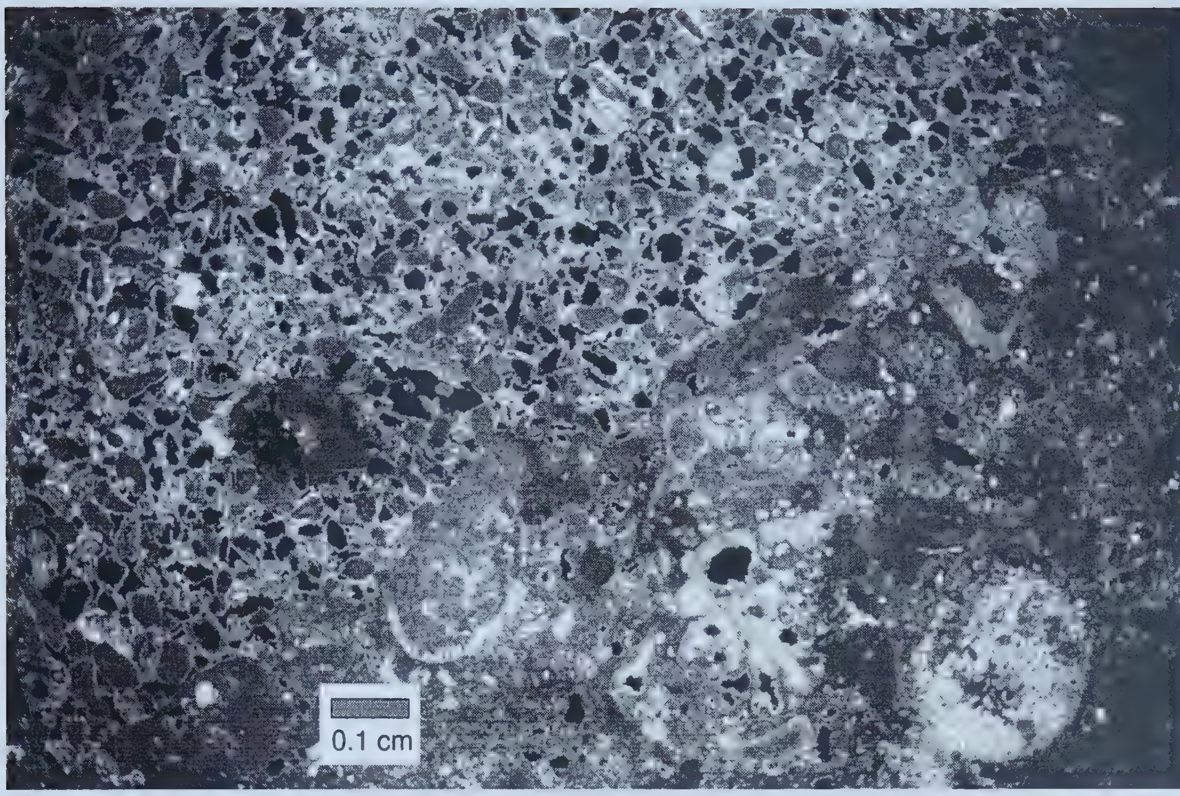


Figure 3.3a. Thin section photomicrograph of a grainstone overlying a hardground developed on a packstone. Ironshore Formation, Member A, RWP #10 at 13.3 m.

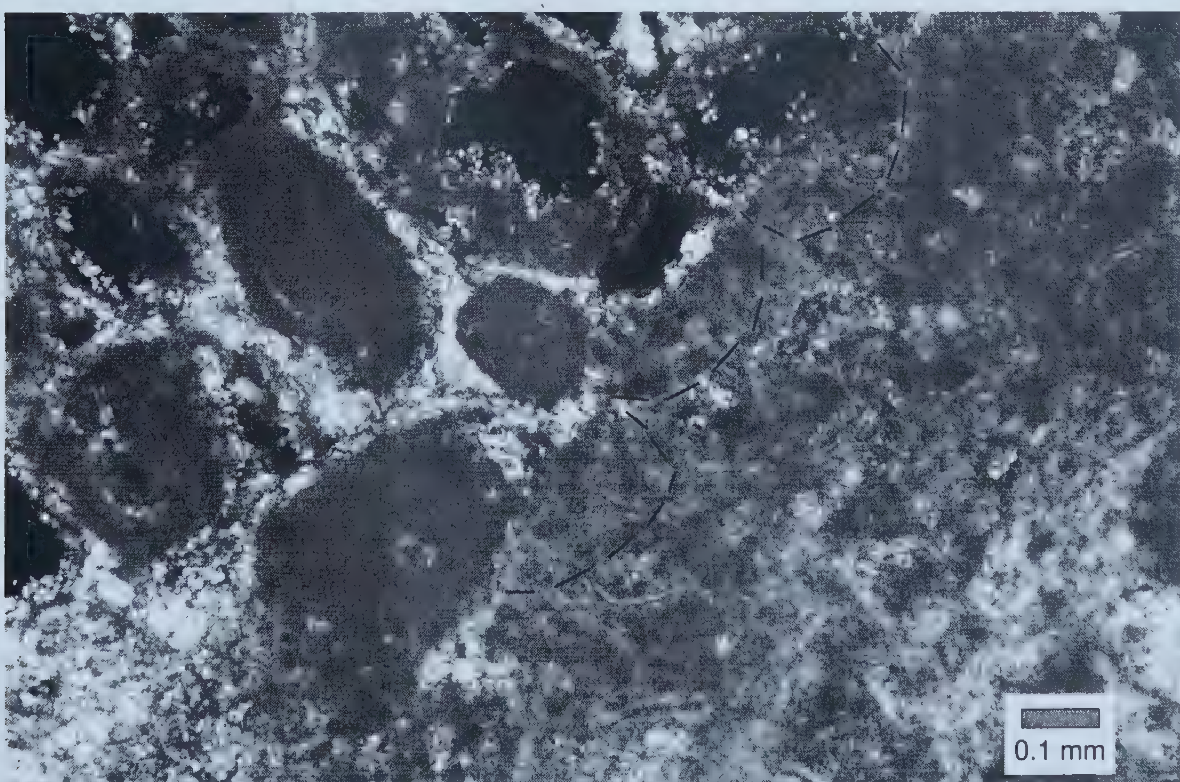


Figure 3.3b. Thin section photomicrograph close-up of the grainstone/packstone contact, note the truncated grains (dashed line) in the packstone. Ironshore Formation, Member A, RWP #10 at 13.3 m.

3.3.2 Interpretation - Member A

Deposition of sediments in Member A was initiated on the hard, eroded substrate of the Tertiary strata (Figure 2.11). Such a substrate would have been ideal for colonization and growth of coral. If an offshore reef had not yet developed (perhaps due to the lag time involved), sediment would have been swept off the shelf, leaving warm, clear, open-marine conditions for the development of a shore-attached fringing reef. The high diversity of coral fauna supports this contention.

The presence of *in situ Acropora palmata* in wells RWP#9 and #14 suggests that shallow water conditions (0-10 m depth) prevailed at the time of their growth. This coral is known to live to depths of 17 m (Hunter, 1994), but is most common in the 0-10 m range. Furthermore, a cross-section through the area (Figure 2.11) reveals a significant break in slope at ~-6 m below psl between wells RWP#4 and #5. The change in slope may have been eroded during a stillstand of sea-level, placing water depth between 4-9 m during the deposition of Member A. This depth estimate is consistent with the depth range of fauna in the unit.

The numerous micritized allochems in the grainstones indicate that the grains spent a considerable time at or near the sediment-water interface. Conversely, many of these grains are also well-rounded and highly-polished, an indication that they have been well-washed and exposed to higher-energy water. The contradiction in implied depositional environments can be explained by assuming quiet-water conditions prevailed for most of the time but were interrupted by relatively short-lived storm events, which re-worked, winnowed, and abraded the grains.

3.3.3 Facies Distribution of Member B

In situ fauna is prevalent north of well RWP#9, whereas the southern area is dominated by grainstones. The 'nearshore' area is characterized by rare mudstones and rudstones interspersed with abundant packstones (Figure 3.4).

Corals in the head coral facies are usually embedded in a packstone or grainstone matrix. In Member B, *Montastrea annularis* and *Siderastrea siderea* are common domal corals in the north (RWP#1, #8, #9, #10, #11, #13, #14, and #15), whereas encrusting or tabular forms of *Porites astreoides* dominate in the south (RWP#2, #3, #4, #5, and #6A). Although *Porites porites* is found throughout the area, it is more common in the south where it makes up a significant proportion of the muddy rudstones.

Sediment size varies laterally throughout the section but sand grains are commonly coarse to very coarse, sub-rounded, and highly micritized. As in Member A, there are no primary sedimentary structures.

Seven of the fourteen wells at Rogers Wreck Point show evidence of caliche development at the top of Member B. Four of these are to the south of the area (RWP#3, #4, #5, and #6A) and three are to the north (RWP#14, #11, and #1).

3.3.4 Interpretation - Member B

Deposition of Member B was initiated on the caliche-capped upper surface of Member A in the north as well as on the hard substrate of the Tertiary strata in the south. Most deposition took place in a quiet, shallow lagoon. Water depth is difficult to ascertain from the coral fauna in Member B, but was probably <10 m based on analogies to present faunal distributions around Grand Cayman.

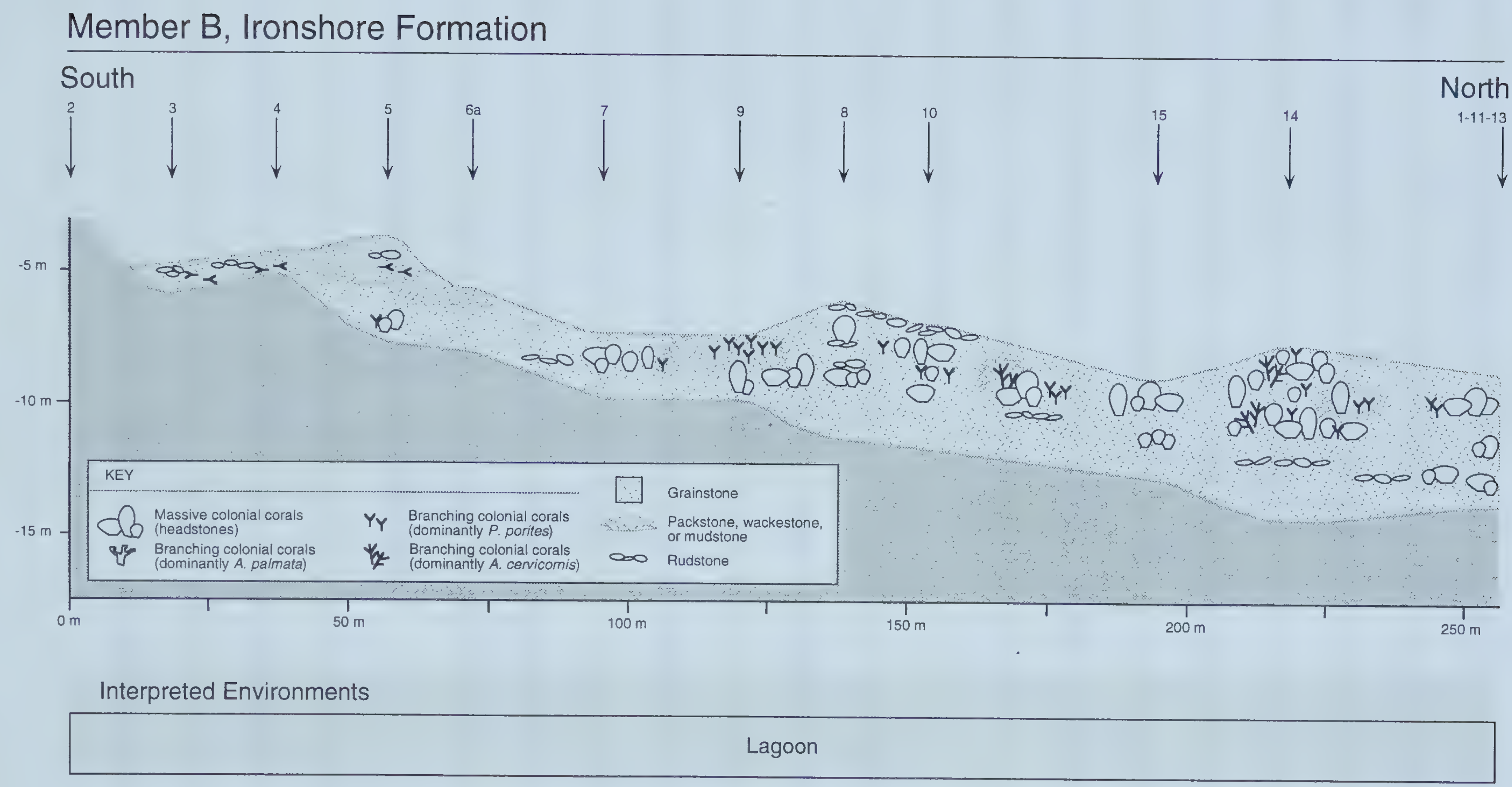


Figure 3.4. Schematic cross-section of the facies distribution in Member B of the Ironshore Formation, Rogers Wreck Point (numbered arrows indicate well locations).

The prevalence of mud-bearing facies in the south and their limited distribution in the north (or seaward) is the opposite to that in Member A, and must therefore reflect a change in the geometry of the depositional system. On this moderately high energy, narrow shelf, a fringing reef, perhaps similar to those that exist around Grand Cayman today, provided restricted shore water energy. Incoming waves would break on the reef and their energy would be dissipated. Consequently grainstones and rudstones dominated on the landward side of the fringing reef. Quiet waters closer to shore allowed muds to settle out of suspension and were conducive to the activities of infaunal organisms such as crabs, worms, and shrimps, which created the structureless sediments, and borers, which resulted in the micritized grains.

There is no direct evidence of a reef crest in Member B. If a fringing reef existed ~346 ka ago at Rogers Wreck Point, and if it was similar in construction to the present-day fringing reef, then it has not been penetrated by any of the wells drilled to date. A recent investigation of the modern fringing reefs around Grand Cayman indicates that they are constructed chiefly of cobbles and boulders derived from *Acropora palmata* (cf. Blanchon, 1995) and that they have relatively narrow crests (usually 10-20 m; Blanchon *et al.*, in press). The reef crest is possibly located between wells or, more probable, it was located further offshore and has since been eroded.

Member B is remarkable for the number of *in situ* head corals that are present. Although they are found fairly regularly throughout core from the north, they are rarely found growing one directly atop the other. This may indicate growth in patch reefs of limited vertical extent, or more likely, that the corals were growing scattered on a coral meadow behind the fringing reef.

A discrepancy between the modern seascape and the proposed scenario of a fringing reef in Member B is the presence of mud in the latter. Mud is rare in the modern lagoons of Grand Cayman (cf. Kalbfleisch, 1995). The sediment of the modern lagoons is winnowed and re-distributed by storms and hurricanes. The presence of mud in sediments of the Ironshore Formation at Rogers Wreck Point indicates that, barring a significant change in the climatic patterns, the mud was bound in place, perhaps by microbial mats. A paucity of direct evidence for the latter is not unexpected considering the decomposition of the organic matter in combination with sediment mixing from bioturbation.

3.3.5 Facies Distribution of Member C

The south of the area (RWP#3-#5) is dominated by grainstones and packstones with minor rudstones that have a muddy matrix (Figure 3.5). *In situ Acropora palmata*, *A. cervicornis*, and a few headstones are minor constituents in the central region (RWP#6a-#15) that is dominated by grainstones and *Porites porites* packstone/rudstone. To the north (RWP#15, #14, #1-11-13), *Acropora cervicornis* and *Porites porites* in life position are directly adjacent to a ~2 m thick sequence of *A. palmata* rudstone. The latter facies may represent the landward edge of a reef crest.

Northern wells, specifically RWP#15, #11, and #13, are dominated by the grainstone facies. In wells RWP#10 to RWP#2 there is an uniform distribution of the grainstone facies and packstone-wackestone-mudstone facies. The average grain size is less than that of Member B. The grains vary in their degree of micritization from micritic envelopes to peloids. As expected, grains having only their outer rim micritized are more prone to

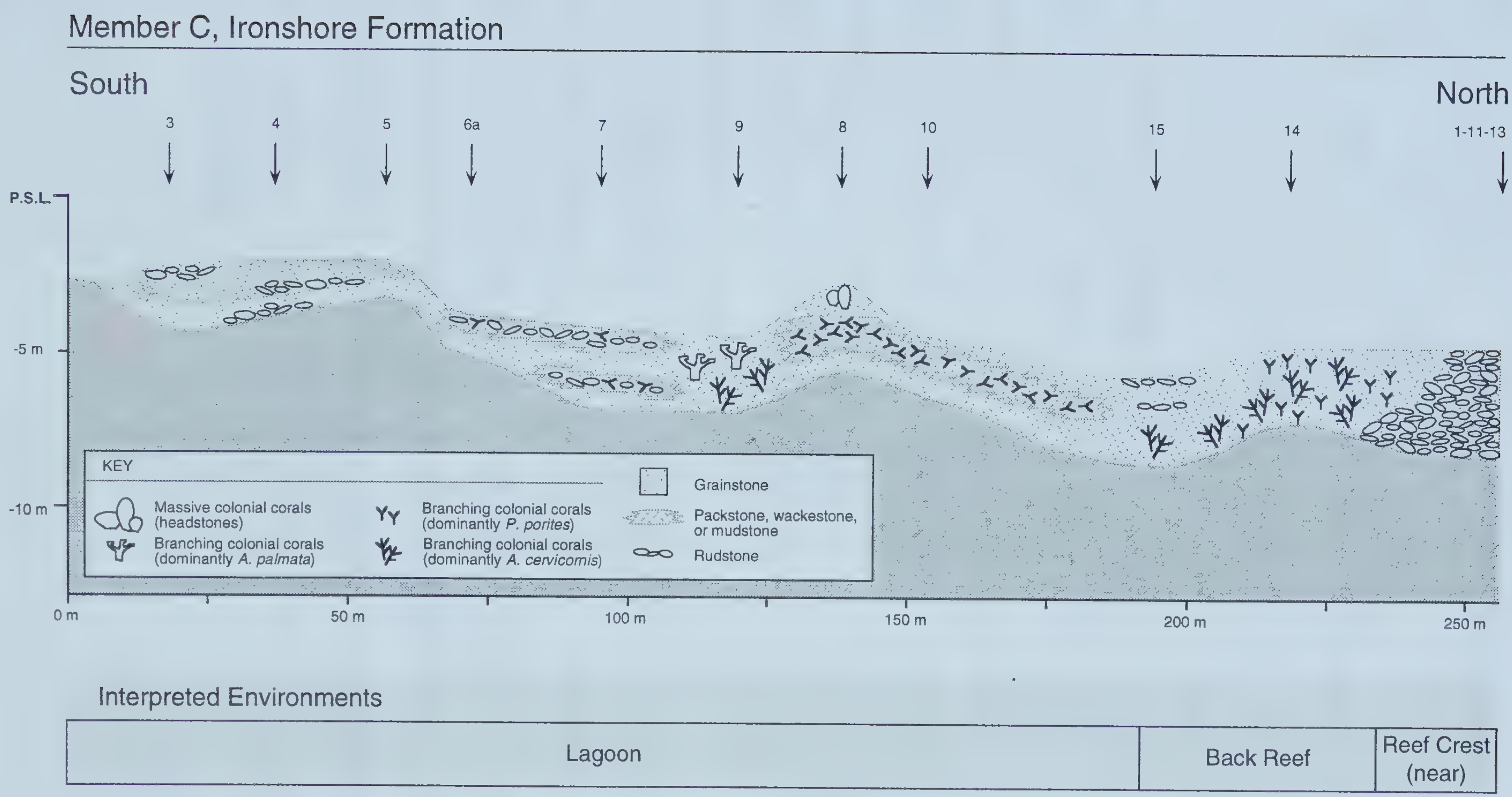


Figure 3.5. Schematic cross-section of the facies distribution, Member C of the Ironshore Formation, Rogers Wreck Point (numbered arrows indicate well locations).

leaching, whereas grains that have been completely micritized are preserved, but are rendered unidentifiable. The degree of abrasion exhibited by the grains varies from little-to-no abrasion to well-rounded grains.

An interesting and as yet unexplained diagenetic characteristic which seems to be more prevalent in Member C is a grey discolouration of the core. The grey colour does not usually persist for more than a metre or two, and is usually near a contact, especially between Member D and Member C (as in wells RWP #7, #8, #15, and #14). Only in RWP#11 is this feature found between Member C and the underlying Member B. Only one of three thin sections made from core with this grey discolouration showed something unusual: ~0.5 mm "patches" of high-relief, cryptocrystalline grey-green material. X-Ray diffraction on a core sample revealed nothing unusual in the composition and the cause of the grey colour could not be identified, although it is presumed to be associated in some way with soil-forming processes.

Seven (RWP#7, #9, #10, #15, #14, #1, and #13) out of fourteen wells show evidence of soil development at the upper contact of Member C. RWP#8 also has some *terra rossa* at the contact between Member C and Member D, but it is unclear if it dates from (1) the hiatus which created the disconformity separating Member C from Member D, (2) the present exposure surface (which is the upper surface of Member D), or (3) both. *Terra rossa* and large, laminated rhizoliths and/or crevices are common throughout the upper half of RWP#8.

3.3.6 Interpretation - Member C

The facies in Member C formed in a quiet, narrow (<250 m) lagoon. The presence of a mixed assemblage containing *in situ Acropora palmata* indicates water depths less than 10 m (Hunter, 1994). This is corroborated by the presence of the reef crest (the 2 m thick *Acropora palmata* rudstone in RWP#11), which in modern settings is located at sea-level.

Member C is characterized by the branching coral facies and the limited presence of the head coral facies (found only in RWP#8, #1, and #13). Perhaps the most significant characteristic of Member C is the ~2 m thick *Acropora palmata* rudstone in RWP#11. Mud-free rudstones, which consist mainly of boulders of *Acropora palmata*, are typical of the present fringing reefs of Grand Cayman (Blanchon, 1995). The rudstones in well RWP#11 may therefore be a fringing reef which has mostly been eroded. Landward (wells RWP#15 and #14) of the fringing reef are *in situ* thickets of *Acropora cervicornis* and some *Porites porites*. This is a similar configuration to some present fringing reef and back-reef communities around Grand Cayman (Rigby and Roberts, 1976; Hunter, 1994; Blanchon, 1995). The few *in situ* corals in the central area (RWP#8 & # 10) may represent small patch reefs and/or isolated corals growing on the sea floor, whereas the branching coral packstones in this region are probably derived from the back-reef community.

The cobble- and boulder-sized components of the mud-bearing rudstones in the south probably result from a combination of storm and bioerosional processes. High energy events such as storms in otherwise quiet water settings commonly cause toppling and displacement of corals that have been weakened at their bases by extensive bioerosion

(*e.g.*, sponges). Normal quiet-water processes generated the common packstone matrix of the rudstones.

3.3.7 Facies Distribution of Member D

Member D outcrops at Rogers Wreck Point, providing a valuable third dimension for study. Thus, information comes from the core and surface mapping of the area.

In general, the core data indicate that Member D is formed primarily of the grainstone facies (Figure 3.6). The packstone-wackestone-mudstone facies is abundant to the south (RWP#2-#7) whereas the grainstone facies is common in the central and north areas (RWP#7-#1-13-11). The rudstone facies is found locally throughout the region. Grain size in these varies from fine to very coarse sands, with cobble-sized material in the rudstones; average grain size is predominantly medium to coarse sand. Grains are only slightly abraded, micritized, and moderately to highly fragmented. Thick pelecypod fragments are found throughout the unit.

The head coral facies, present throughout most of the area, is most abundant in the north (RWP#15 & #14), where it can form up to half the thickness of Member D. *Montastrea annularis* and *Siderastrea siderea* are the dominant species in the north, with some *Diploria* sp. The assemblage diversifies southward to include *Porites astreoides* and *Diploria* sp., with rare *Favia fagrum,* and *Dichocoenia stokesi*. The branching coral facies, found only in RWP#9, consists of *Porites porites* and *Acropora cervicornis* with rare *A. palmata* and *Goniapora* sp. Branching corals are, however, a significant component in many of the packstones and mud-bearing rudstones.

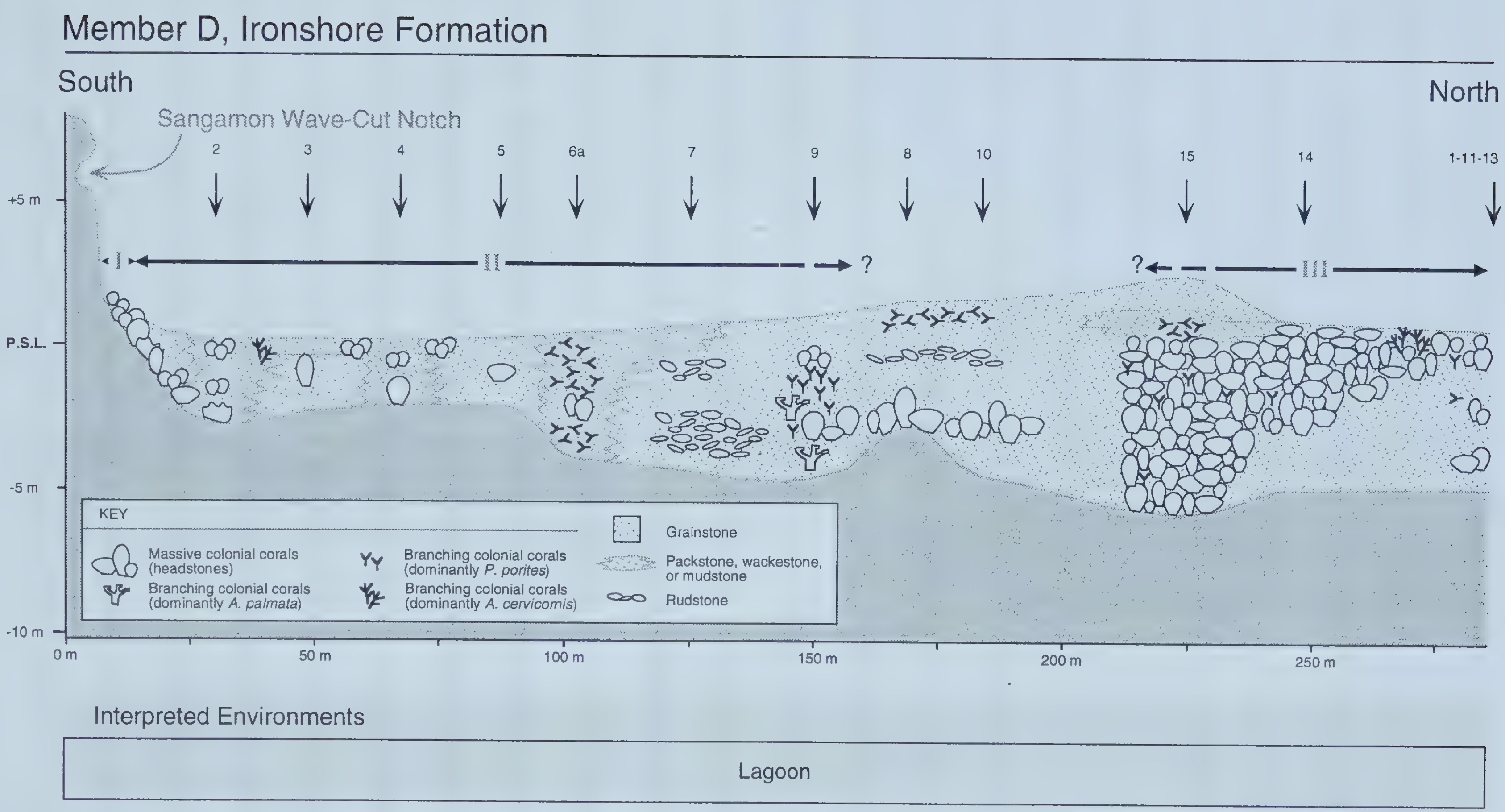


Figure 3.6. Schematic cross-section of the facies distribution in Member D of the Ironshore Formation, Rogers Wreck Point (numbered arrows indicate well locations). Zones I, II, and III are surface mapping areas; vegetation covers the northern portion of Zone II and the southern portion of Zone III.

All the corals are well preserved, most still having their aragonitic skeletons. As in the other units, most corals were encrusted with thick layers (up to 3 cm) of red algae and foraminifera (especially *Carpenteria* sp. and *Homotrema* sp.), and were bored by sponges and pelecypods (Figure 3.7). The branching coral facies is limited to RWP#9 and #13.

The grey discolouration described in Member C (3.3.5), present at the base of two wells (RWP#7 and #14) and part way down two others (RWP#2 and #8), appears to be associated with the exposure surface.

Inspection of the surface area around Rogers Wreck Point shows that there are three zones stretching from the Tertiary cliff to the present-day coast (south to north) (Figure 3.8). Zone I, ~3-5 m wide and located at the base of the cliff, consists of several varieties of head corals that are up to 80 cm in diameter. These corals, which are attached to or encrust the base of the cliff, include *Siderastrea* sp., *Diploria strigosa*, *D. clivosa*, *Agaricia* sp., and *Porites astreoides*. Gastropods are abundant in the matrix.

Zone II, ~150 m to~250 m wide, stretches from the Queen's Highway to at least RWP#9. Much of this surface, though calcretized, was covered in what appeared to be a fine sand. Where the matrix was not completely obscured by the calcrete, numerous bivalve and gastropod shells are evident. Some areas, measuring up to 2 m^2, but commonly 1 m^2, contain numerous small head corals (10-20 cm), and scattered branching corals. Locally these patch reefs have a greater variety of corals, but usually there is one dominant genus (typically *Montastrea annularis* or *Diploria* sp.), with heads up to 70 cm in diameter. Corals in these small patches include *Mycetophyllia ferox*, *Diploria strigosa*, *Montastrea annularis*, *Manicina areolata, Acropora cervicornis* (rare), *Eusmilia fastigiata*, and *Porites porites*. In the area around RWP#2 an outcrop which is 1 m above

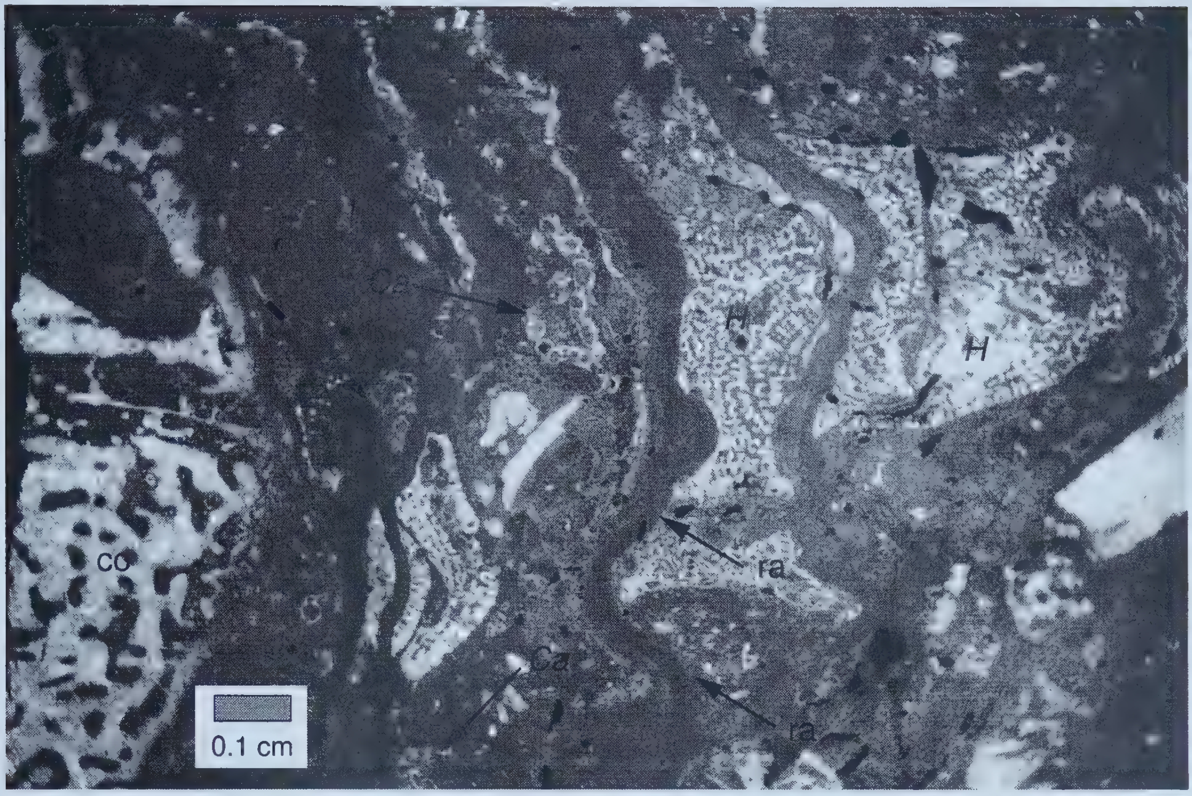


Figure 3.7. Thin section photomicrograph of Homotrema (H), red algae (ra), and Carpenteria (Ca) encrusting a coral (co). Ironshore Formation, Member A, RWP #8 at surface.

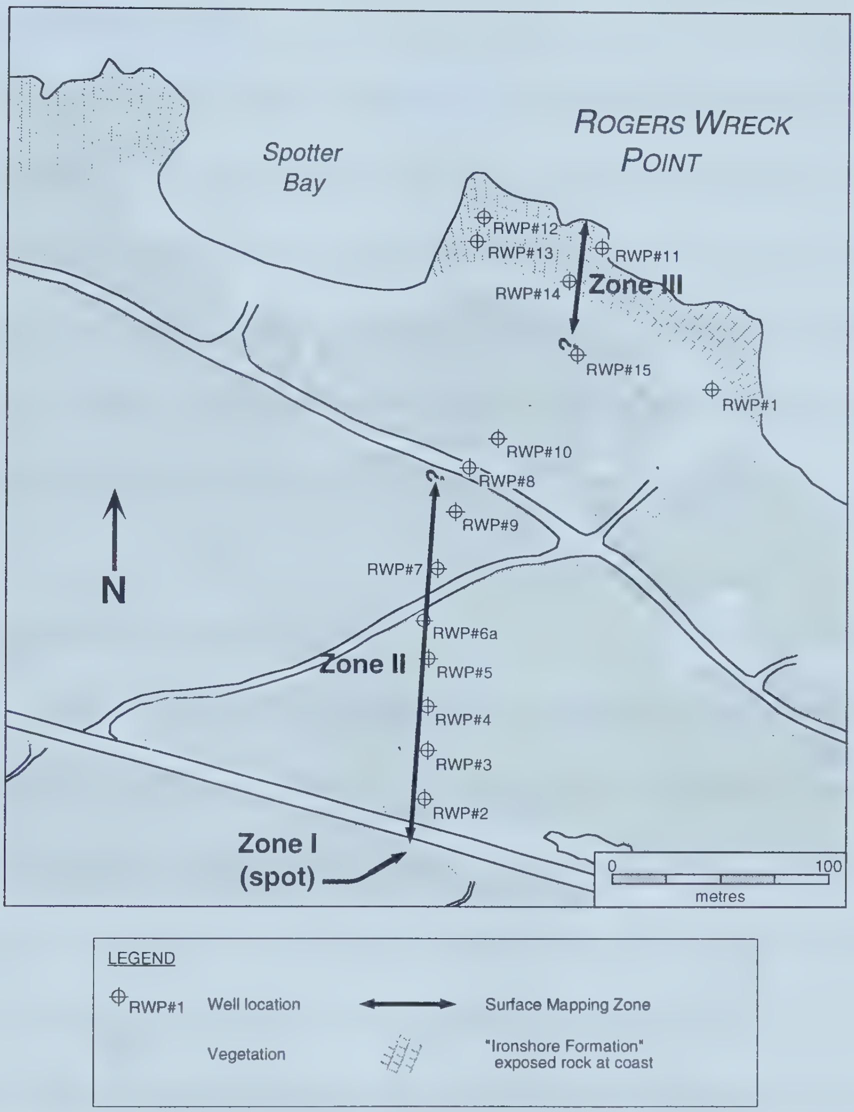


Figure 3.8. Surface mapping zones at Rogers Wreck Point.

the surrounding ground consisted of a colony of *Acropora cervicornis* with some *Porites porites*. This outcrop was ~8 m long and 2 m wide, and lay parallel to the present shoreline (and thus the bluff).

Zone III, ~40-50 m in width, is located north of RWP#15 and extends to the present coast. Corals, which are considerably more numerous than in Zone II, are held in a sandy matrix; they include *Favia fagrum*, *Montastrea annularis*, *M. cavernosa*, *Acropora cervicornis*, *A. palmata*, *Agaricia* sp., *Diploria strigosa*, *Isophyllastria rigida*, and *Goniapora* sp. Some of the larger head corals (*eg.; Montastrea annularis*) are almost 80 cm in diameter, but most are generally 20-30 cm in diameter.

3.3.8 Interpretation - Member D

Member D was deposited over the Cayman Formation and the caliche-hardened upper surface of Member C on a narrow, cliff-lined shelf. Deposition took place in a sandy lagoon in shallow water depths. Biota type and distribution suggest water depths were <15 m. This can be further refined to a minimum water depth of ~3.5 m because a wave-cut notch at +6 m was formed from the same highstand event.

Zone I, where the large head corals are attached to the cliff base, was probably a moderately high-energy environment as a result of the turbulence from waves crashing into the cliffs. A similar environment is present today just to the west of Rogers Wreck Point. There, bluffs of the Cayman Formation form the present-day coastline and waves crashing into them create water turbulence. Pedro Castle Point, along the south coast of Grand Cayman, provides a second example. Very little sediment is present in outcrop in this zone, partly because the corals here grow directly one atop the other. The lack of

sediment may also be an indication that it was either never deposited (swept away by the turbulent water) or that it has since been eroded. The latter suggestion is likely considering that in this depositional regime it was probably a grainstone and thus quite friable.

Abundant packstones and wackstones in core to the south (RWP#2-7, or ~Zone II) indicate quiet water processes and/or the presence of microbial mats. The slight abrasion and high micritization of the allochems in the grainstones corroborates this interpretation. Corals in this area are scattered. Surface exposures indicate that the patches of coral, dominantly headstones, have a limited lateral extent whereas the core indicates they have a limited vertical extent. These may represent small, poorly-developed patch reefs. The diversity of corals and allochems in the sands and their distributions are similar to those of modern lagoons on Grand Cayman such as East Sound and Frank Sound.

The concentration of head corals in core and at the surface to the north of RWP#15 (~Zone III) suggests that this area was kept free of significant sediment deposition, and therefore subjected to higher energy than the area to the south. Furthermore, the distribution of the corals in RWP#15, #14, and #1-11-13 suggests that coral growth was initially vertical but then extended laterally in a seaward direction. This distribution could have resulted from an initial "keep-up" phase of the corals with a rising sea-level, and then a shift to lateral growth following sea-level stabilization.

Although there are numerous head corals in Zone III, this zone is also characterized by an inter-mixing of head and branching corals not seen elsewhere on the surface of the study area. Nowhere in Zone III, however, in either outcrop or core, is there evidence of the crest of a fringing reef. Certainly the abundance of sands and muds present in Zone II

indicates that some sort of structure was present to dampen the offshore waves crashing onto the headland. The corals and their distribution are similar to some coral communities situated directly behind the fringing reefs which presently exist on Grand Cayman, such as at Rum Point (Rigby and Roberts, 1976). It is possible, then, that a fringing reef was present 130 ka ago in what is now offshore, but has probably since been eroded by the most recent sea-level rise.

3.4 Synopsis

Deposition of the four members of the Ironshore Formation at Rogers Wreck Point took place on a moderately high-energy, narrow shelf on the north-east coast of Grand Cayman. The members share the same components and facies, but in varying distributions.

Member A was deposited in shallow water, open marine conditions on the eroded surface of Tertiary strata. It contains a diverse coral fauna and lacks any distinct spatial distribution of the facies. Member B was deposited in a quiet, shallow lagoon, and contains numerous head corals. Deposition took place on the caliche-capped surface of Member A and on the hard substrate of the Tertiary strata. Member C was deposited in a quiet, shallow lagoon and contains numerous branching corals. Evidence of a reef crest, the only one identified in any of the members, is found at the far north of the study area. Member D was deposited in a quiet lagoon in water depths ranging from 3.5-12 m. Scattered, small patch reefs in the south progress to a more abundant and diverse mix of fauna seaward.

Chapter IV:

400 ka Record of Sea-Level Highstands From Rogers Wreck Point, Grand Cayman

4.1 Introduction

Identifying the magnitude and timing of sea-level fluctuations during the Pleistocene and Quaternary is critical for any assessment of future climate variability. Concerns over possible future global warming as a result of anthropogenic addition of CO_2 to the atmosphere has been the impetus for concern about sea-level rise (Hansen *et al.*, 1981; National Academy of Sciences/National Research Council, NAS/NRC, 1979, 1982). In order to assess the impact humans are having on the climate, and thus future variability, the natural variability of the system must first be deciphered.

Two main techniques have been used to decipher Quaternary sea-level fluctuations. First, $^{18}O/^{16}O$ ratios from biogenic calcite in deep sea cores were used to determine paleo-oceanographic temperatures and paleo-climatic conditions (Emiliani, 1955; Shackelton and Opdyke, 1976). Second, periods of sea-level highstands have been recognized from uplifted coral-reef terraces (Broecker *et al.*, 1968; Mesollela *et al.*, 1969; Veeh and Chappell, 1970; Konishi *et al.*, 1970; James *et al.*, 1971; Bloom *et al.*, 1974; Neef and Veeh, 1977; Szabo *et al.*, 1978) (Table 4.1). Uplift rates for the terraces were determined (and corrected for) following the improvement of radiometric dating. Results from both techniques demonstrated a cyclicity in sea-level fluctuations which was attributed to orbital forcing (Mesolella *et al.*, 1969; James *et al.*, 1971; Shackelton and Opdyke, 1973; Imbrie *et al.*, 1984).

There are limitations to the sea-level curves constructed using $\delta^{18}O$ and uplifted coral-reef terraces. Although the $\delta^{18}O$ record extends back to the Cretaceous, it has a poorly constrained chronology between ~350 ka BP (the upper limit of Th/U dating) and ~780 ka BP (the Brunhes-Matuyama magnetic reversal) due to the paucity of radiometric

Location	Age(s) (BP)	Method(s)	Estimate of paleosea-level (relative to today)	Comments	Source
Barbados	82 ka	Th/U + He/U			Bender *et al.* , 1979
	105 ka	Th/U + He/U			Bender *et al.* , 1979
	125 ka	Th/U + He/U			Bender *et al.* , 1979
	180 ka	Th/U + He/U			Bender *et al.* , 1979
	200 ka	Th/U + Hc/U			Bender *et al.* , 1979
	220 ka	Th/U + He/U	~psl	• large errors involved	Bender *et al.* , 1979
	300 ka	Th/U + He/U	~psl (±10 m)	• large errors involved	Bender *et al.* , 1979
	320 ka	Th/U + He/U	~psl (±10 m)	• large errors involved	Bender *et al.* , 1979
	Undated	Th/U + He/U	~psl	• large errors involved	Bender *et al.* , 1979
	490 ka	Th/U + He/U	~psl	• large errors involved	Bender *et al.* , 1979
	460 ka	Th/U + He/U	~psl	• large errors involved	Bender *et al.* , 1979
	520 ka	Th/U + He/U	~psl	• large errors involved	Bender *et al.* , 1979
	590 ka	Th/U + He/U	~psl	• large errors involved	Bender *et al.* , 1979
	640 la	Th/U + He/U	~psl (±22 m)	• large errors involved	Bender *et al.* , 1979
	60 ka	Th/U	not estimated	• corals and gastropods	James *et al.* , 1971
	82 ka	Th/U	~-14 m		Broecker *et al.* , 1968
	103 ka	Th/U	~-12 m		Broecker *et al.* , 1968
	122 ka	Th/U	+6 m	• sea-level elevation assumed	Broecker *et al.* , 1968
	82 ka	Th/U	~-15 m		Matthews, 1973
	105 ka	Th/U	~-16 m		Matthews, 1973
	125 ka	Th/U	~+6 m		Matthews, 1973
	<125 ka, >105 ka		-71 m ± 11 m	• borehole data	Steinen *et al.* , 1973
	82 ka	Th/U	not estimated		Mesolella *et al.* , 1969
	105 ka	Th/U	not estimated		Mesolella *et al.* , 1969
	125 ka	Th/U	not estimated		Mesolella *et al.* , 1969
	170-230 ka	Th/U	not estimated	• 2-3 terraces formed	Mesolella *et al.* , 1969
	>250 ka	Th/U	not estimated	• several terraces in this time frame	Mesolella *et al.* , 1969
Bermuda	~130 ka	Th/U	<+3.0 m		Hearty & Vacher, 1994
	~200 ka	AAR	~+2.3 m	• eolianites	Hearty & Vacher, 1994
	~330 ka	AAR	~+3.8 m	• eolianites	Hearty & Vacher, 1994
	~450 ka	AAR	~+4.0 m	• eolianites	Hearty & Vacher, 1994
	>700-1100 ka	AAR	not estimated	• shells from *terra rossas*	Hearty & Vacher, 1994

Table 4.1: Age estimates of Pleistocene sea-levels from uplifted and stable platforms.

Location	Age(s) (BP)	Method(s)	Estimate of paleosea-level (relative to today)	Comments	Source
	125 ka	Th/U	+4 to +6 m	• corals; wave cut notch	Harmon *et al.* , 1981
Bahamas	125 ka	Th/U	+5.3 to +5.9 m	• "bioerosional" notch	Neumann & Moore, 1975
San Salvadore Island	150-100 ka	Th/U	not estimated	• 1 long event or 3 separate events	Carew & Mylroie, 1987
	~49 ka	Th/U	~psl	• speleothems	Carew & Mylroie, 1987
	~85 ka	AAR	<-2 m	• eolianites	Carew & Mylroie,1987
	>700 ka	paleomagnetism	not estimated	• caliches	Carew & Mylroie, 1987
Great Inagua Island	122-125 ka	Th/U			White & Curran, 1991
Andros Island	0.7 to 3.2 Ma	Magnetostratigraphic		• eleven distinct events recognized	McNeill & Ginsburg, 1988
Jamaica	~130 ka	isotopic	not estimated	• = Terrace 1	Cant, 1972
	~200-310 ka	altimetric	not estimated	• = Terrace 2	Cant, 1972
	Cromerian III intergl.		not estimated	• = Terrace 3	Cant, 1972
	Prior to Brunhes	paleomagnetic	not estimated	• = Terrace 4	Cant, 1972
	125 ka		+5 m		Boss & Liddell, 1987
Haiti	130 ka	Th/U	+6 m	• coral	Dodge *et al.* , 1983
	108 ka	Th/U	-10 m	• coral	Dodge *et al.* , 1983
	81 ka	Th/U	-13 m	• coral	Dodge *et al.* , 1983
Cayman Islands	120-130 ka	ref'd dates (Th/U)	+6 m	• wave-cut notch and sedimentology	Jones & Hunter, 1990
	~124 ka	Th/U	+2 m	• corals	Woodroffe, 1983
Grand Cayman	~125 ka	Th/U	+2 m	• *Strombus* shells embedded in reef	Emery, 1981
Yucatan Peninsula	122 ka	Th/U	+5 to +6 m	• dated corals	Szabo *et al.* , 1978
Florida					
Key Largo Island	~130 ka	Th/U	+10 m	• dated corals	Osmond *et al.* , 1965
Curaçao & La Blanquilla	130 ka	Th/U	not estimated	• sampled corals	Schubert & Szabo, 1978
	~325 ka	Th/U	not estimated	• dates uncertain due to alteration	Schubert & Szabo, 1978
	~570 ka	Th/U	not estimated	• dates uncertain due to alteration	Schubert & Szabo, 1978

Table 4.1: Age estimates of Pleistocene sea-levels from uplifted and stable platforms.

Location	Age(s) (BP)	Method(s)	Estimate of paleosea-level (relative to today)	Comments	Source
Eniwetok Atoll	6 ka	Th/U	not estimated	• corals and oolites	Thurber *et al.* , 1965
	120 ka	Th/U	not estimated	• corals and oolites	Thurber *et al.* , 1965
Huon Peninsula, New Guinea	30 ka	Th/U			Chappell, 1974
	40-50 ka	Th/U			Chappell, 1974
	60 ka	Th/U			Chappell, 1974
	80 ka	Th/U	referenced others' values		Chappell, 1974
	105 ka	Th/U	referenced others' values		Chappell. 1974
	120 ka	Th/U	+2 - +10 m		Chappell, 1974
	140 ka	Th/U	presumed to be psl		Chappell, 1974
	185 ka	Th/U	presumed to be psl		Chappell, 1974
	220 ka	Th/U	presumed to be psl		Chappell, 1974
	220-400 ka	projected uplift rate	presumed to be psl		Chappell, 1974
	8-6,6 ka	oxygen isotope ratios	not estimated	• = Terrace I	Aharon, 1983
	28.5 ka	oxygen isotope ratios	not estimated	• = Terrace II	Aharon, 1983
	51 and 37 ka	oxygen isotope ratios	not estimated	• = Terrace III(a) & III(b)	Aharon, 1983
	60 ka	oxygen isotope ratios	not estimated	• = Terrace IV	Aharon, 1983
	85 ka	oxygen isotope ratios	not estimated	• = Terrace V	Aharon, 1983
	107 ka	oxygen isotope ratios	not estimated	• = Terrace VI	Aharon, 1983
	133 and 120 ka	oxygen isotope ratios	not estimated	• = Terrace VII(a) & VII(b)	Aharon, 1983
	5-9 ka	Th/U	~-8 m	• Reef complex I	Bloom *et al.* , 1974
	29 ka	C^{14}	-41 m	• Reef complex II	Bloom *et al.* , 1974
	41 ka	Th/U	-38 m	• Reef complex IIIb	Bloom *et al.* , 1974
	61 ka	Th/U	-28 m	• Reef complex IV	Bloom *et al.* , 1974
	85 ka	Th/U	-16 to -30 m	• Reef complex V	Bloom *et al.* , 1974
	107 ka	Th/U	-20 to -8 m	• Reef complex VI	Bloom *et al.* , 1974
	~124 ka	Th/U	+2 to +12 m	• Reef complex VIIb	Bloom *et al.* , 1974

Table 4.1: Age estimates of Pleistocene sea-levels from uplifted and stable platforms.

dating control. Sedimentation rates have been used to estimate the chronology, but the rates are variable and there is the problem of vertical layers of sediment being mixed from bioturbation. To address this situation a marine $\delta^{18}O$ record (SPECMAP) was developed by combining data from five deep-sea cores and filtering out the "noise" created by local disturbances and/or variations in the sedimentation rate (Imbrie *et al.*, 1984). The oxygen isotope ratios used to construct this curve were obtained from planktonic foraminifera, but the controls on the $^{16}O/^{18}O$ composition of an assemblage of planktonic foraminifera is poorly understood (Shackelton, 1987). In light of this problem, benthic foraminifera are now preferred because they provide a less complicated record of global ice volume. Recently it has been shown, however, that even bottom waters vary during some ice ages, thus affecting benthic forams as well (Chappell and Shackelton, 1986).

There are several problems associated with sea-levels estimated from uplifted terraces. Whereas it is obvious that there are terraces that must pre-date the Sangamonian Interglacial, they are almost all impossible to date radiometrically. Diagenetic alteration of aragonitic components in the rocks from these terraces increases with age and precludes accurate dates (*e.g.,* Thurber et al., 1965; Mesolella *et al.*, 1969; Schubert and Szabo, 1978; Bloom *et al.*, 1974; Aharon, 1983). Also, the application of a constant rate of uplift is necessary in order to calculate the paleosea-levels.

Traditionally, the two locations most used in discussions on elevated reef terraces and sea-levels are Barbados and New Guinea. Both locations have multiple terraces, but only late Pleistocene (~<200 ka BP) carbonates are accurately dateable. Beyond ~250 ka BP, diagenetic alteration introduces large errors to the dates. Furthermore, both islands have undergone differential uplift (Bender *et al.*, 1979; Chappell, 1974). Nevertheless, uplifted terraces on Barbados provided the best sea-level proxy with the potential for absolute dates. The older terraces were dated at ~640 ka BP using Th/U and He/U methods (Bender *et al.*, 1979) (Table 4.1). The numerous corrections applied to this dating method meant that the error margins on sea-level estimates for middle Pleistocene

dates are so large (in some cases on the order of ±22 m) that the only conclusion reached was that high sea-levels between 250 ka BP and 640 ka BP were similar to present sea-level (Bender *et al.*, 1979).

New Guinea has more than 20 reef complexes (Chappell, 1974; Bloom *et al.*, 1974). Most studies of the Huon Peninsula involving sea-level estimates, however, concentrated on the terrraces that are younger than ~130 ka BP as a result of intense meteoric alteration of the older terraces (Table 4.1). In fact, in order to estimate the ages of the older terraces, Chappell (1974) projected an uplift rate beyond 220 ka BP using the assumption that sea-levels for the older terraces were similar to present sea-levels.

Where possible then, a combination of data from uplifted terraces and deep-sea cores has so far provided the best data for sea-level estimates over the last 220 ka. Beyond the range of dating of the uplifted terraces, however, reliance is placed on the deep-sea oxygen isotope record. The four members in the Ironshore Formation identified at Rogers Wreck Point on Grand Cayman may represent a record of relative sea-level change that encompasses the last four interglacial periods. The degree to which this record reflects changes in eustatic sea-level, however, depends on the tectonic stability of Grand Cayman. It must therefore be ascertained if the four members in the Ironshore Formation at Rogers Wreck Point formed in response to (1) eustatic sea-level changes, or (2) changes in the elevation of the island due to tectonism.

4.2 Tectonic Stability of Grand Cayman Over the Last 500 ka

Grand Cayman is situated in an active tectonic zone that separates the North American Plate from the Caribbean Plate. The island's position on a horst block (the Cayman Ridge) bound by planar faults (Lewis *et al.*, 1990) isolates it from

transpressional/transgressional stresses that cause uplift or subsidence (Mann *et al.*, 1990). Given the setting, substantial and aperiodic tectonic movement of Grand Cayman might be expected. Nevertheless, available evidence from Grand Cayman suggests that the Tertiary strata are probably horizontal. Certainly, the Tertiary strata on Grand Cayman have not been tilted to the degree found on Cayman Brac. There, interpretation of vaguely defined planes in the Bluff Group indicate that this island is tilted ~0.5° to the west (Jones, 1994). It must have also been subjected to significant uplift in order for the contact between the Cayman and Brac formations to become visible in the vertical cliffs at the east end of the island. In contrast, this contact has not yet been discovered on Grand Cayman, even though recent drilling (April 1996) has reached sub-sea depths of ~130 m (Jones, pers. comm., 1996).

Jones and Hunter (1990) suggested that Grand Cayman has been tectonically stable since the last interglacial ~125 ka BP. They argued that sea-level maximum ~125 ka ago was +6 m relative to present sea-level based on the presence of a wave-cut notch found at several localities on Grand Cayman. At Rogers Wreck Point and Old Man Village the notch is well-defined, with the maximum incision at +6 m. At Blow Holes, on the south-east coast, this notch is subtle because subsequent erosion has destroyed much of the bedrock. A well-defined notch is also present at +6 m on Cayman Brac (Jones, 1994). Tilting and uplift on Cayman Brac must have take place prior to the 125 ka highstand because the +6 m wave-cut notch formed while sediments of the Ironshore Formation were being deposited. Available evidence indicates that Cayman Brac is on a different fault block than Grand Cayman (Matley, 1926; Horsfield, 1975).

Evidence for the stability of Grand Cayman can be extended to 5 Ma BP. Karst that formed on the Cayman Formation ~5 Ma BP created relief of up to 41 m on this unit (Jones and Hunter, 1994). There is no evidence of tilting of those features. Subsequent deposition of the Pedro Castle Formation ~2 Ma BP was largely controlled by the antecedant topography developed on the Cayman Formation (Jones and Hunter, 1994). The Pedro Castle Formation appears to have filled-in the bowl-shaped depression of the Cayman Unconformity (Figure 4.1). Despite post-Pedro Castle Formation karst development, the upper surface of the Pedro Castle Formation is characterized by little relief (Figure 4.1). It seems probable, therefore, that the position of the Cayman and Pedro Castle formations, and the unconformities that separate them, reflect the effects of eustacy and karsting rather than vertical, tectonically induced movement of Grand Cayman. Thus, despite its proximity to the Cayman Trench, an active spreading center, Grand Cayman appears to have been tectonically stable for the last 5 Ma (Blanchon and Jones, 1995).

4.3 Sea-Level Estimates from Rogers Wreck Point Data

Available evidence indicates that Grand Cayman has been stable for at least the last 500 ka. Therefore, the four members of the Ironshore Formation at Rogers Wreck Point must have formed in response to eustatic changes in sea-level. Thus, each unconformity between the successive members must provide an estimate of the sea-level position at its time of deposition. Assuming little erosional modification, a minimum sea-level elevation for each sequence is determined from the highest elevation of the deposits in each unit (Table 4.2).

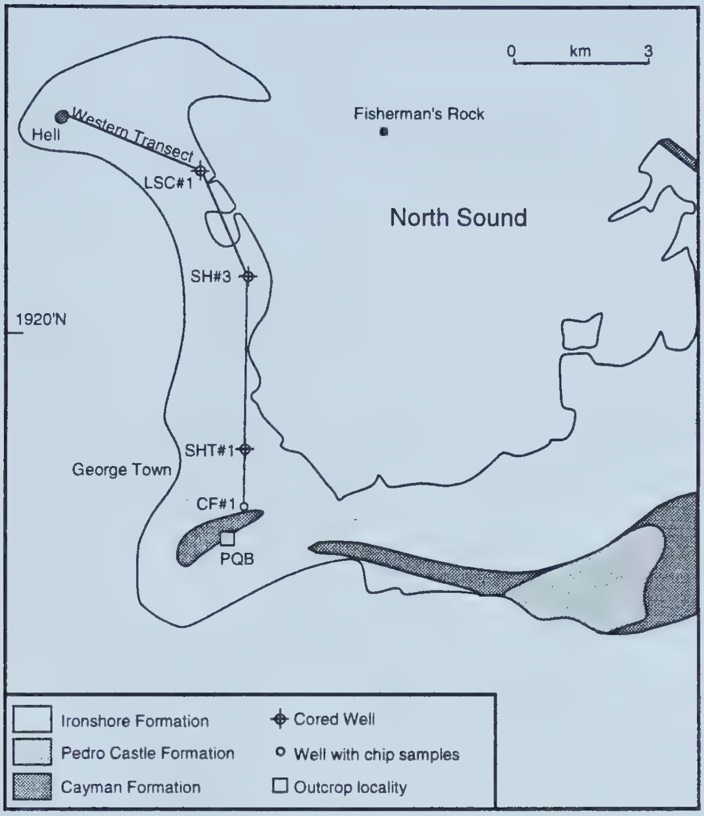


Figure 4.1 (a). Map of the western part of Grand Cayman showing the location of the Western Transect (modified from Jones and Hunter, 1994).

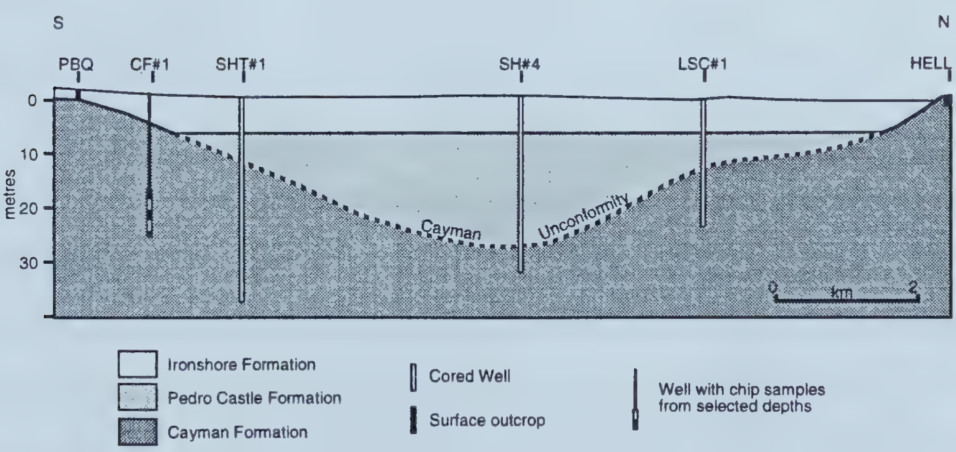


Figure 4.1 (b). Stratigraphic relationships between the Cayman, Pedro Castle, and Ironshore Formations along the Western Transect. Note the nearly horizontal nature of the upper surfaces of the Ironshore and Pedro Castle formations (modified from Jones and Hunter, 1994).

Table 4.2. Minimum sea-level estimates for members A, B, C, and D of the Ironshore Formation at Rogers Wreck Point, Grand Cayman.

Unit	Age (BP)	~ Minimum Sea-Level (relative to present msl)
A	>400 ka	-9.2 m
B	~346 ka	-3.0 m
C	~232 ka	-2.4 m
D	~131 ka	+2.6 m

The validity of assuming that minor, if any, erosional modifications have been made to the upper surface of each unit is open to debate. The sediments were deposited during sea-level highstands. During the intervening lowstands, soils and caliches developed on the upper surface deposits of each unit. Erosional effects are minimal during regressive events, however, so most erosion would have taken place during the (1) subaerial exposure of the units, or (2) succeeding sea-level transgression. It is difficult to assess the amount of erosion that may have taken place as a result of subaerial processes. It is evident from the core that caliche was forming at Rogers Wreck Point. The formation of such a crust on the upper surfaces of these units probably protected the rock and prevented further erosion (Spencer *et al.*, 1984). The formation of a dense crust on the surface prevents rainwater from percolating through the highly porous and typically friable sediments, and results instead in increased surface run-off. Furthermore, the recovery of the caliches from the upper surface of *each* member of the Ironshore Formation at Rogers Wreck Point indicates that erosion associated with subsequent rise in sea-level did not remove much of the units. Therefore it appears that little sediment/rock was removed from each member of the Ironshore Formation at Rogers Wreck Point.

Sea-level estimates made using the upper surface of each member imply that the top of each unit was deposited *at* sea-level. This is unlikely because it assumes that sediments accumulate up to sea-level. A more precise set of values can be assessed by considering the facies and sedimentology of the units. The corals found in all four

members are associated with mid-shelf scarp depths on Grand Cayman, or ~10 m of water or less (Hunter, 1994). The sedimentology and facies distribution of the units is also consistent with such water depths. The estimate of ~10 m can be further refined, however, by considering the relationship between Member D and the sea-level position for the Sangamon. Sea-level elevation ~130 ka BP has been established at ~+6 m from many localities throughout the world (*e.g.*, Matthews, 1973; Neumann and Moore, 1975; Harmon *et al.*, 1981; Carew *et al.*, 1984; Brasier and Donahue, 1985) and is supported by the wave-cut notch on Grand Cayman (Hunter and Jones, 1988; Jones and Hunter, 1990). The difference between the elevation of the uppermost deposits of Member D and the wave-cut notch is ~3.5 m. This further emphasizes that the position of the upper bounding unconformity does not give the precise location of sea-level. Considering the similarities in sedimentology between the four members, a more accurate sea-level estimate for each unit might be obtained by adding 3.5 m to the minimum estimate (Table 4.3).

Table 4.3. Adjusted estimates for sea-level elevation for Members A, B, C, and D of the Ironshore Formation at Rogers Wreck Point, Grand Cayman.

Unit	Age (BP)	Estimated Minimum Sea-Level	Sea-level Correction	Estimated Sea-Level, Adjusted
A	>400 ka	-9.2 m	+3.5 m	-5.7 m
B	~346 ka	-3.0 m	+3.5 m	+0.5 m
C	~229 ka	-2.4 m	+3.5 m	+1.1 m
D	~131 ka	+2.6 m	+3.4 m	+6.0 m

When the adjusted sea-level elevations are plotted on cross-sections of Rogers Wreck Point (Figures 4.2, 4.3, 4.4, and 4.5), some interesting features become apparent. First, the adjusted sea-level estimate for Member A coincides with a break in slope in the underlying Tertiary strata (Figure 4.2). The change in slope between wells RWP#3 and RWP#5 might be an erosional feature associated with a sea-level stand-still. Alternatively, it may be a constructional feature associated with the underlying Cayman

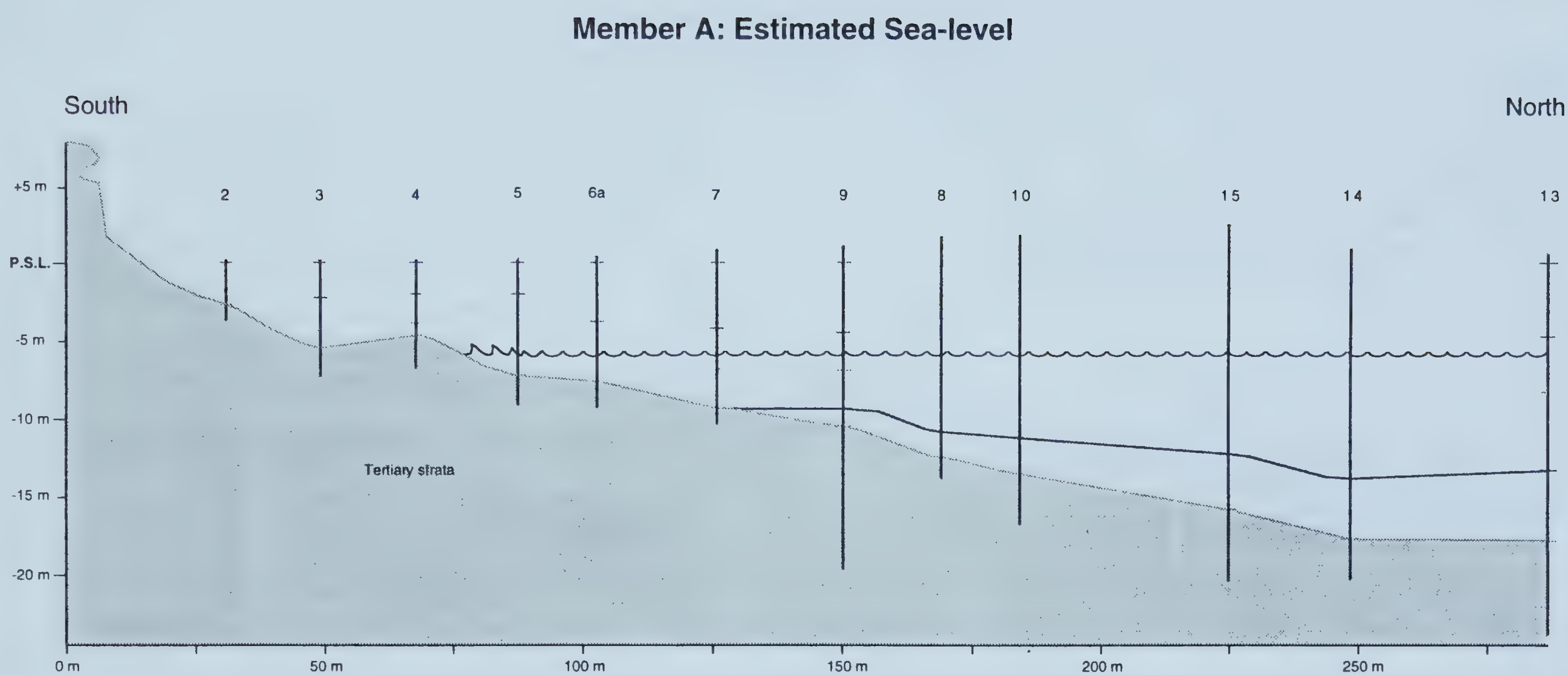


Figure 4.2. Schematic cross-section illustrating the estimated sea-level (-5.7 m) for Member A of the Ironshore Formation at ~400 ka BP.

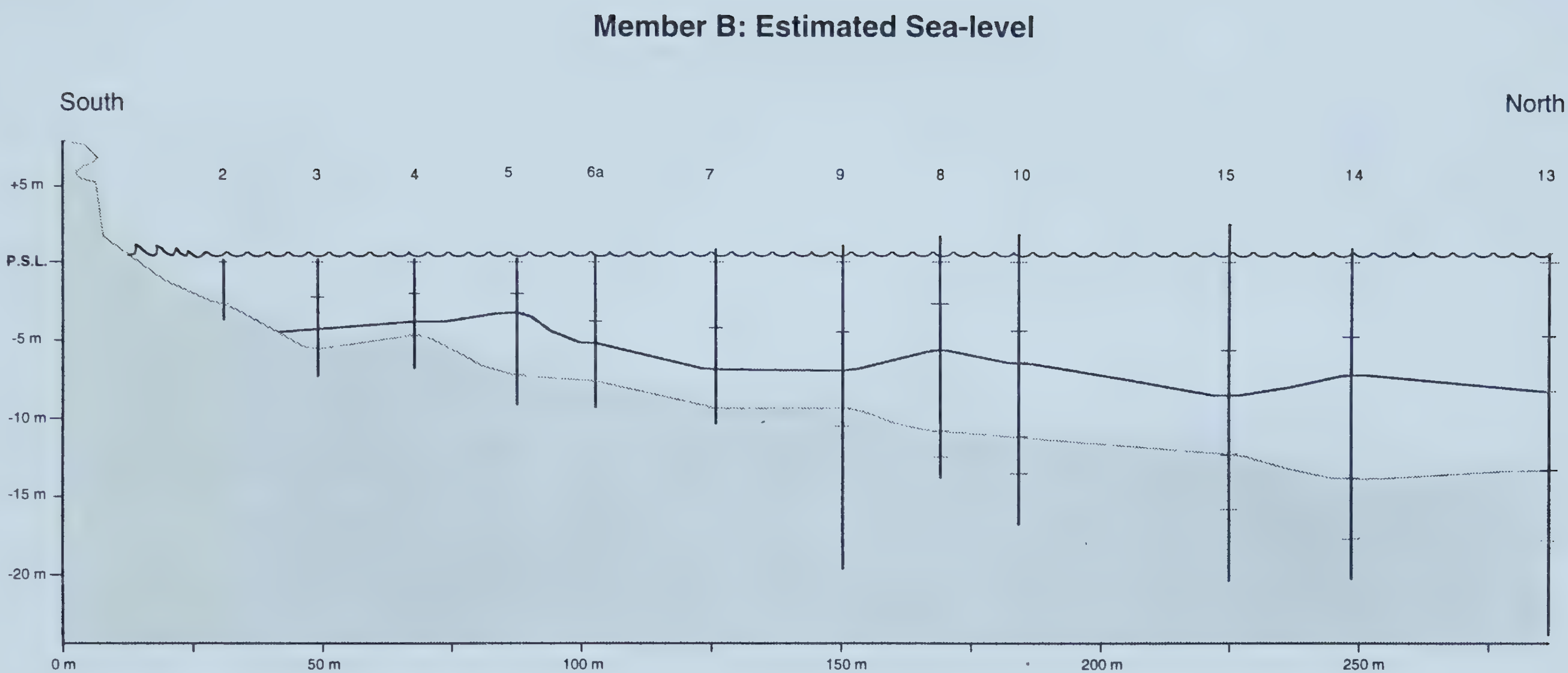


Figure 4.3. Schematic cross-section illustrating the estimated sea-level (+0.5 m) for Member B of the Ironshore Formation at ~346 ka BP.

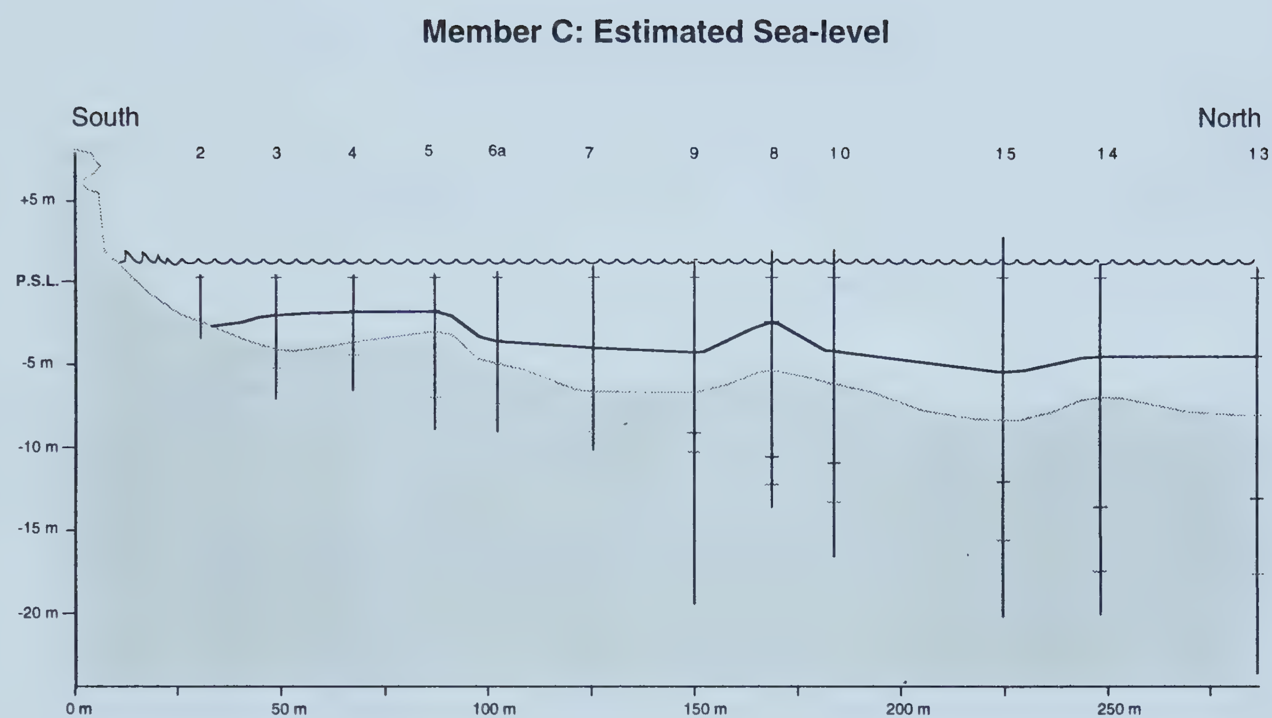


Figure 4.4. Schematic cross-section illustrating the estimated sea-level (+1.1 m) for Member C of the Ironshore Formation at ~232 ka BP.

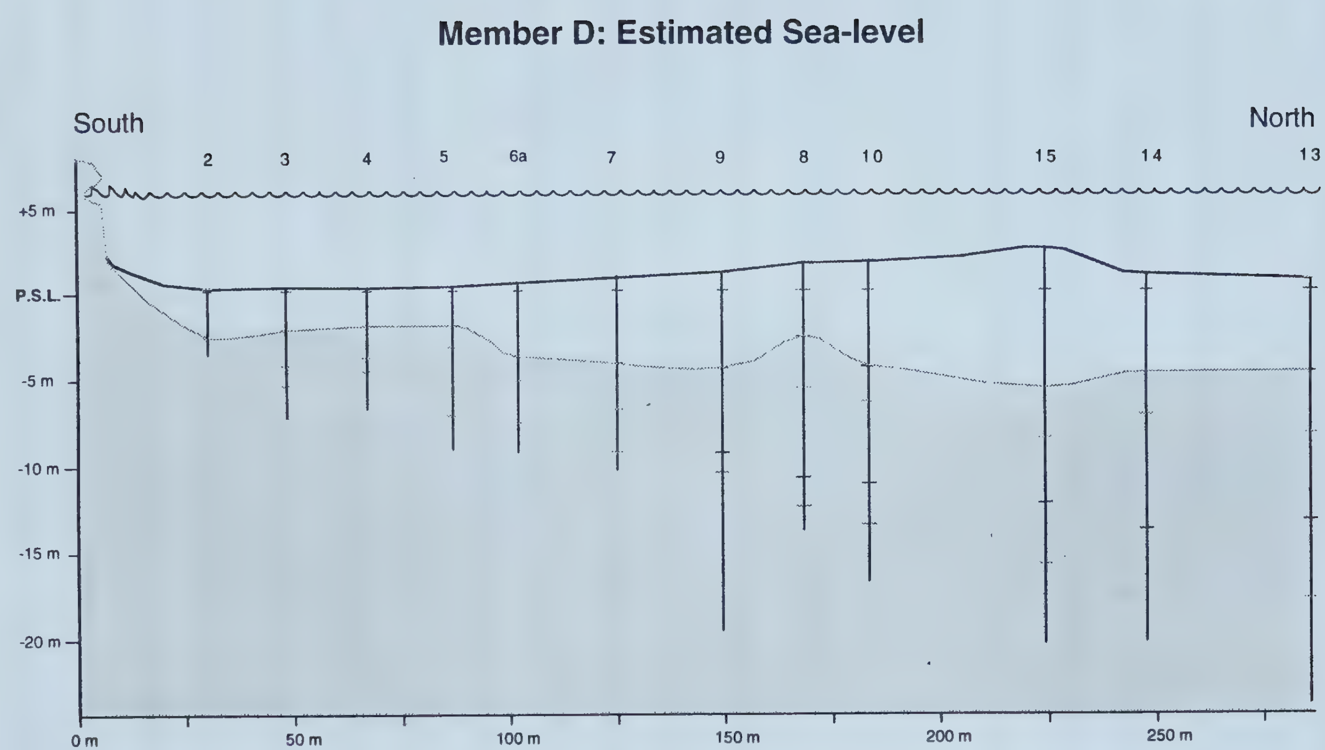


Figure 4.5. Schematic cross-section illustrating the estimated sea-level (+6.0 m) for Member D of the Ironshore Formation at ~131 ka BP.

Formation. A sedimentalogical analysis of the Cayman Formation from RWP#4, however, shows that this is not the case. Thus, the break in slope may represent the paleoshoreline for the >400 ka BP unit. Second, the adjusted estimates for Members B and C (with only 0.6 m difference between them) place paleosea-level for these two units just above the base of the cliff of Tertiary strata (Figures 4.3 and 4.4). This cliff must have existed prior to the deposition of Member D ~130 ka BP in order for the notch at +6 m to be there. The combined action of two sea-level still-stands at the same elevation might have been enough to create the relatively prominent bluffs at Rogers Wreck Point. When sea-level rose again ~130 ka ago, the surf cut a notch into the relatively steep cliff face (Figure 4.5).

4.4 Comparisons with Data From Other Areas/Methods

Assessing sea-level elevation for a given epoch requires a set of radiometric dates from geographically dispersed locations for strandlines at places accepted as tectonically stable. In order to compare the interglacial sea-level estimates from the units on Grand Cayman, other locations and/or methods must be sought that offer a time scale on the order of 500 ka BP. Locations considered tectonically stable include the Bahamas, Bermuda, various Pacific islands, west Australia, and the Seychelles (Chappell, 1974). Unfortunately, there is typically a paucity of data from these locations on a time scale suitable for comparison with the units from Rogers Wreck Point (Table 4.1).

The preferred case for comparison of data would be another series of unconformities separating carbonate units on a different stable island. Unfortunately, this situation has not yet been described from the Caribbean. Comparisons with tectonically-elevated coral terraces might be in order because they are relatively common and well-studied (*e.g.*, Barbados, Jamaica, Huon Peninsula, Ryukyu Islands). Unfortunately the inability to obtain accurate radiometric dates from terraces older than ~250 ka makes this method ineffectual for comparing sea-levels for members A (>400 ka BP) and B (~346 ka BP) to

the uplifted terraces. However, comparisons with data from members C and D are possible.

4.4.1 Data from Uplifted Terraces

Bermuda and New Guinea have the most complete record of sea-level fluctuations for the mid-to-late Pleistocene (Table 4.1). Relatively accurate radiometric dates from these uplifted terraces are available back to 250 ka BP. Dates in this range that overlap between Grand Cayman, Barbados, and New Guinea are those of 229 ka BP and 131 ka BP (Members C and D, respectively) (Table 4.4).

Table 4.4. Tentative correlation of highstands at Rogers Wreck Point, Grand Cayman, with highstands represented by uplifted terraces from Barbados and New Guinea. ('?' indicates greater uncertainty in the correlation)

Barbados	New Guinea	Rogers Wreck Point
	30 ka BP (Chappell, 1974)	
	40-50 ka BP (Chappell, 1974)	
60 ka BP (James et al., 1971)	60 ka BP (Chappell, 1974)	
82 ka BP (Bender et al., 1979)	80 ka BP (Chappell, 1974)	
105 ka BP (Bender et al., 1979)	105 ka BP (Chappell, 1974)	
125 ka BP (Bender et al., 1979)	? 120 ka BP (Chappell, 1974)	~131 ka BP (this study)
	? 140 ka BP (Chappell, 1974)	
180 ka BP (Bender et al., 1979)	185 ka BP (Chappell, 1974)	
200 ka BP (Bender et al., 1979)		
220 ka BP (Bender et al., 1979)	220 ka BP (Chappell, 1974)	~229 ka BP (this study)

Sea-level for the ~131 ka BP highstand has been previously determined to be +6 m. Sea-level at ~229 ka BP from Rogers Wreck Point is estimated at +1.1 m relative to psl. For this period, Bender *et al.* (1979) obtained estimates of +2 m and +14 to +17 m relative to psl for this time period from separate traverses on Barbados. The discrepancy in his estimates indicate that there are problems with the calculated differential uplift rates on Barbados for this time period (Bender *et al.*, 1979). Chappell (1983) calculated sea-

level position on New Guinea ~220 ka ago to be -10 m relative to psl. This estimate is substantially different than that obtained from Rogers Wreck Point, where the upper surface of Member C (age ~229 ka BP) at is at -2.4 m relative to psl. Chappell's (1983) estimate may reflect dating and uplift problems on New Guinea.

4.4.2 Data from Stable Islands

There are very few data from stable islands extending beyond ~130 ka. A recent examination of the accretionary stratigraphy of Bermuda using amino acid racemization dating, however, yielded ages of ~130 ka BP, ~200 ka BP, ~300 ka BP, and ~450 ka BP for the last four interglacials (Hearty and Vacher; 1994) (Table 4.5). Hearty and Vacher (1994) used low-angle bedding, intertidal sedimentary structures, and trace fossils to estimate sea-level positions.

Table 4.5. Data summarized from Hearty and Vacher (1994).

Aminozone	Formation	Marine Isotope Stage	Age range (ka BP)	Age (ka BP)	Maximum sea-level (m)
E	Rocky Bay	5e	118-135	~130	<+3.0
F	Belmont	7	190-265	~200	~+2.3
G	Upper Town Hill	9	300-400	~330	~+3.8
H	Lower Town Hill	11	400-500	~450	~+4.0

The conclusions from the Bermudian sequences are pertinent to the data from Rogers Wreck Point. A remarkable correlation exists between the three middle-Pleistocene reef sequences at Rogers Wreck Point and the eolianite deposits as described by Hearty and Vacher (1994) on Bermuda. In both cases the interglacial cycles are individually bracketed by *terra rossa* paleosols. The ages of the individual units correlate well; differences between them are probably attributable to dating and sampling techniques. Furthermore, the general thicknesses of the individual units are similar: Member B and the Upper Town Hill Formation (Marine Isotope Stage 9) both appear to represent an interglacial of

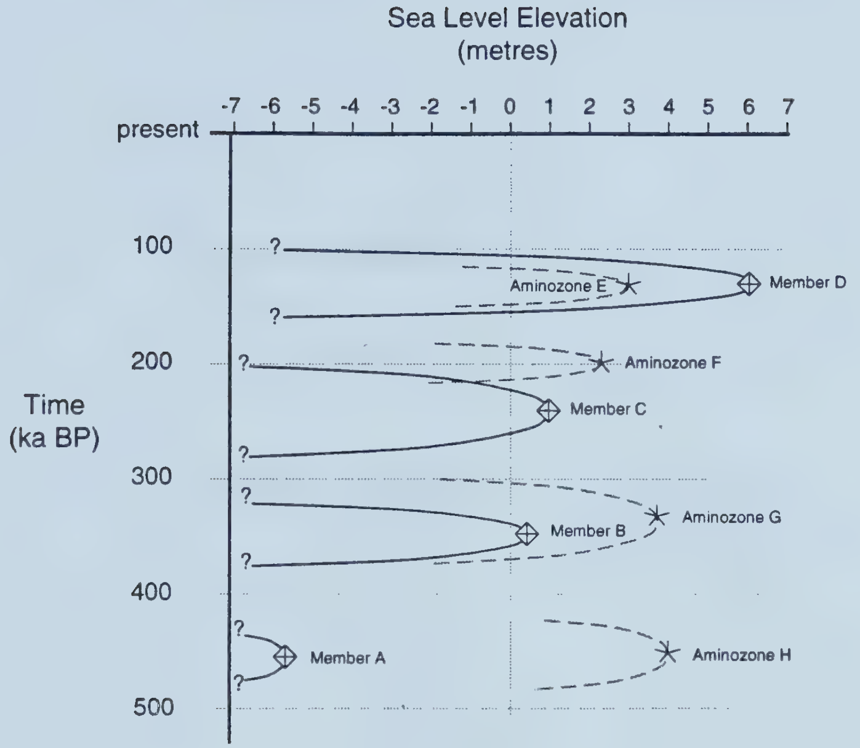
significant duration, comparable to the Sangamonian event in terms of volume of sediment deposited.

Besides the good correlation between the ages of interglacial units, the estimations of absolute elevation of sea-level during these interglacials are similar. Differences in sea-level assessments are attributable to the techniques involved; the two different approaches yield slight differences in sea-level estimates (Figure 4.6).

4.4.3 Oxygen Isotope Data

Probably the most widely accepted global evidence for eustatic sea-level fluctuations in the Pleistocene comes from $\delta^{18}O$ variations in the sediment of deep-sea cores. The ratio of ^{18}O to ^{16}O is related to the amount of water held in polar ice caps during glacial/interglacial cycles (Shackelton, 1977).

When the ages of the units at Rogers Wreck Point are plotted on the SPECMAP $\delta^{18}O$ curve (Figure 4.7) it confirms that members A, B, C, and D represent the last four major interglacials. Member D corresponds to the early stages of the Marine Isotope Stage 5 interglacial. Member C falls between the first two peaks of the Marine Isotope Stage 7 interglacial. The margin of error on the dates from Member C means this unit could be associated with either peak. The 'youngest' peak (at ~195-200 ka BP) of the Marine Isotope Stage 7 interglacial on the isotope curve is 'higher' than the first two peaks. This suggests that sea-level was higher at this time (post-deposition of Member C) than during the two 'older' peaks. There is no evidence at Rogers Wreck Point, however, of deposition or erosion from a highstand associated with the higher, younger (195-200 ka BP) peak. Member B has only one radiometric date, which probably corresponds to Marine Isotope Stage 9. Member A is the unit for which we have the poorest age constraints because it approaches the limits of the dating method. Although Member A could be associated with any highstand between 400 ka BP and 1.7 Ma BP (based on radiometric dating and the coral *Acropora palmata*), it probably represents



Sea-level estimates from Rogers Wreck Point; this study.

Sea-level estimates from Bermuda; Hearty and Vacher, 1994.

Figure 4.6. Sea-level comparison of radiometric dating (this study) and amino acid racemization from Bermuda (Hearty and Vacher, 1994).

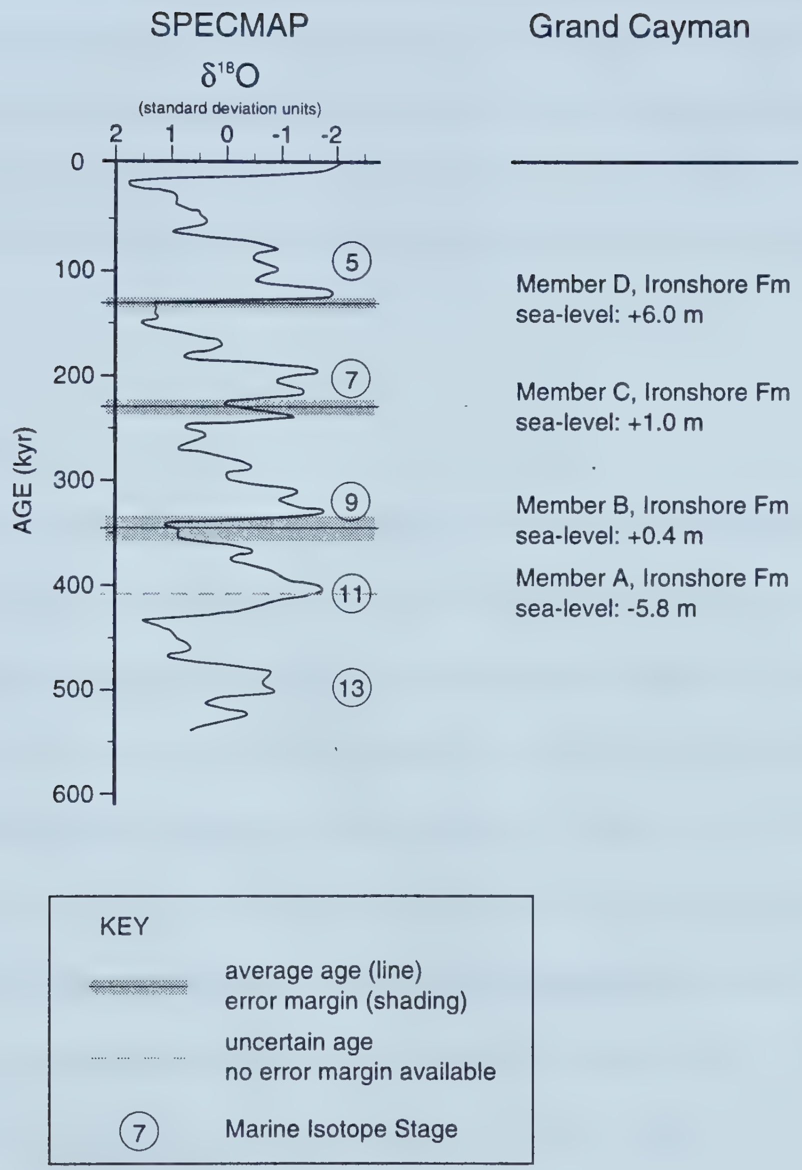


Figure 4.7. Correlation of dates from Rogers Wreck Point with the SPECMAP time scale and the Marine Isotope Stages (modified from Imbrie *et al.*, 1984).

Marine Isotope Stage 11. This correlation seems reasonable considering that members B, C, and D correspond with the high peaks of the next three consecutive interglacials. Moreover, if the SECMAP curve is accurate, sea-level elevation associated with the interglacial represented by Marine Isotope Stage 13 (~500 ka BP) was considerably lower than the next four interglacials (MIS 11, 9, 7, and 5). Paleosea-level estimates from the Ironshore Formation at Rogers Wreck Point are within 12 m of each other. Therefore Member A has been tentatively correlated with the beginning of the transgression at ~425 ka BP.

4.5 Synopsis

There has probably been little to no tectonic uplift on Grand Cayman for at least 500 ka despite its proximity to an active spreading center. The four Pleistocene units on Grand Cayman, individually delineated by subaerial exposure surfaces, are thus the first described examples of carbonate reef development on a stable platform which are associated with sea-level changes controlled primarily by orbital forcing. The four members of the Ironshore Formation at Rogers Wreck Point represent the last four interglacials (Table 4.6). They are also the only reef systems yet described which still retain material suitable for accurate radiometric dating beyond 250 ka.

Table 4.6. Summary of the depositional record of the last 400 ka on Grand Cayman.

Member	Age (ka BP)	Sea-level (m)	Marine Isotope Stage
D	~131	+6.0	5
C	~229	+1.1	7
B	~346	+0.5	9
A	>400	-5.7	11

CHAPTER V:

CONCLUSIONS

A study of the Pleistocene Ironshore Formation at Rogers Wreck Point has produced the following important conclusions.

(1) The Ironshore Formation consists of four, unconformity-bounded members (A, B, C, and D) that were deposited during highstands >400 ka BP (Member A), ~346 ka BP (Member B), ~229 ka BP (Member C), and ~131 ka BP (Member D).

(2) Deposition of the Ironshore Fomation in the Rogers Wreck Point area took place on a narrow coastal shelf. The oldest unit (Member A) was deposited in an open-marine setting. The three younger units (members B, C and D) were deposited in a lagoonal environment that was probably protected by fringing reefs at the seaward edge of the shelf.

(3) The unconformities that form the boundaries of the members are highlighted by caliche and/or *terra rossa*. These unconformities may be lacunas that represent intraglacial periods.

(4) Available data indicate that the paleosea-levels for each unit, relative to present-day sea-level, are: Member A, -5.7 m; Member B, +0.5 m; Member C, +1.1 m; and Member D, +6.0 m. This assumes that Grand Cayman has not been affected by vertical tectonic movements over the last 500 ka.

(5) The four members of the Ironshore Formation represent the highest elevations of sea-level attained during the last four interglacial periods that are correlated with Marine Isotope Stages 5, 7, 9, and 11.

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APPENDIX A

WELL LOGS

Legend

Corals

- *Montastrea* sp.
- *Siderastrea* sp.
- *Diploria* sp.
- *Favia fragum*
- *Acropora palmata*
- *Dichocoenia stokesi*
- *Acropora cervicornis*
- *Dendrogyra cylindricus*
- *Porites porites*
- *Agaricia* sp.
- *Porites astreoides*

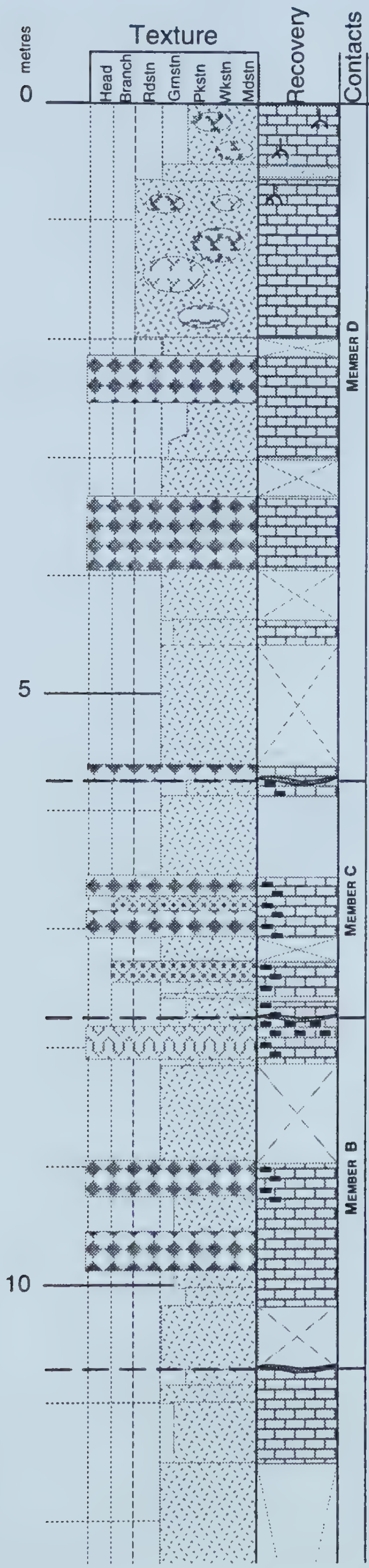
Rock Type

- Grainstone
- Packstone/Wackestone/Mudstone
- Rudstone

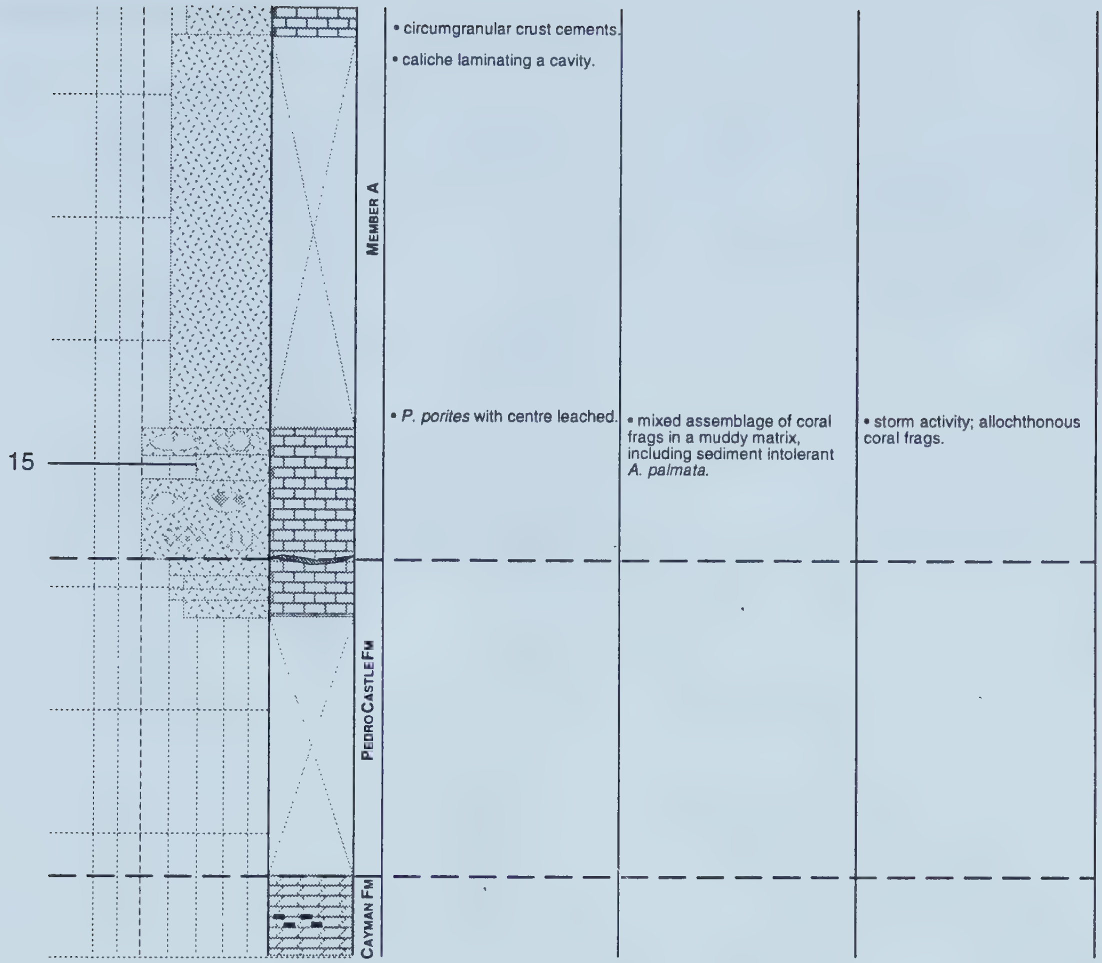
Accessories

- *terra rossa*
- rhizoliths
- caliche

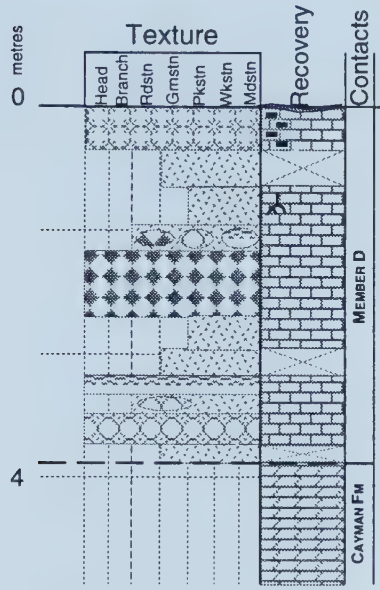
Rogers Wreck Point #1



	Description	Significant Features	Interpretation
Member D	• rhizoliths common; allochem textures obscured by caliche fabrics. • coral frags bored extensively. • skeletal grains = abundant encrusters • grains micritized.	• ubiquitously bored and encrusted branching coral rubble in a pkstn matrix. • *in situ* head corals with grnstn and pkstn matrix; matrix dominated by encrusting organisms. • sand-dominated.	• dominantly quite water. • probable storm-toppled corals; corals show unusually high level of bioerosion.
Member C	• *M. annularis* and *A. palmata in situ.* • inter-coral spaces have laminated sides, and *terra rossa* found in some leached coral centres.	• mud at the top • presence of *in situ A. palmata*, a coral which is incapable of sediment rejection. • mud present.	• energy fluctuation from low (mud) to high (*in situ A. palmata*), and back to low (mud).
Member B	• *terra rossa* stained grnstn. • *Diploria* framework porosity filled by *terra rossa*. • above grnstn: somewhat rounded grains; 100% bioerosion; 0% articulation; 80% fragmentation. • leached grains are sub-rounded. • spongy texture brown from *terra rossa*. • micrite envelopes remain. • sed fine-grained and abraded.	• *terra rossa*. • *in situ* head corals with abraded, bioeroded, fragmented grnstns and fine-grained pkstns to poorly-washed grnstn. • mud present.	• soil developed, exposure surface. • mainly quiet water processes; storms indicated by redistribution and abrasion of grains.
	• core well indurated; appears more crystalline (aragonite to low Mg calcite). • circumgranular crust cements. • caliche laminating a cavity.	• sand-dominated. • poor core recovery. • no *in situ* corals.	• high sedimentation rate; not conducive to coral growth.

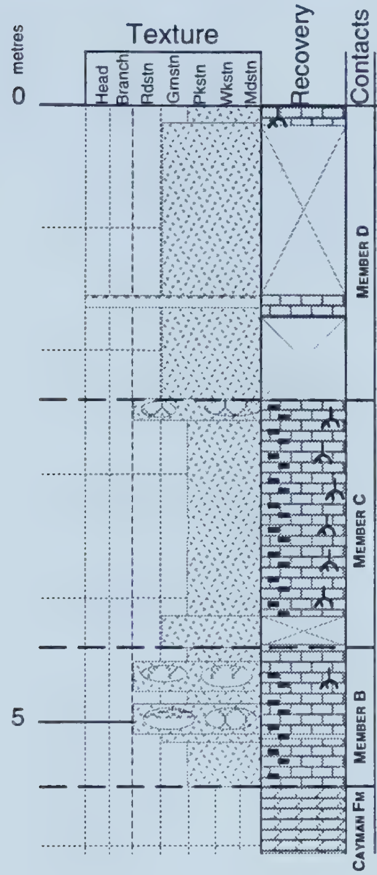

• circumgranular crust cements.
• caliche laminating a cavity.
MEMBER A
15
• P. porites with centre leached.
• mixed assemblage of coral frags in a muddy matrix, including sediment intolerant A. palmata.
• storm activity; allochthonous coral frags.
PEDRO CASTLE FM
CAYMAN FM

Rogers Wreck Point #2



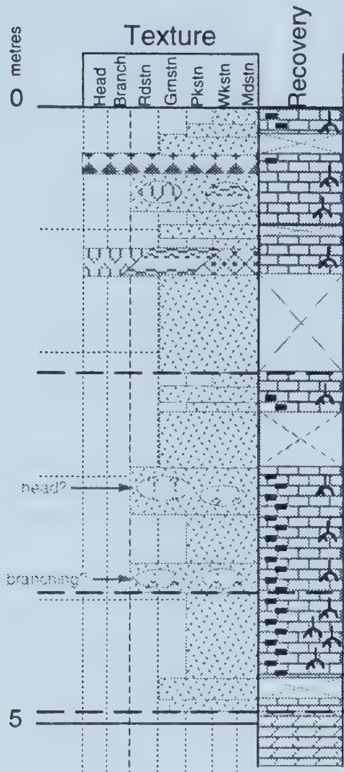
Description	Significant Features	Interpretation
• *terra rossa* in corals. • thick shells. • mud matrix with skeletal grains; abundant encrusters. • fine-grained allochems. • clear cements line some pores. • pebbles of Cayman Fm?	• *terra rossa*, rhizoliths. • mud throughout. • diverse assemblage of head corals.	• exposure surface. • dominantly quiet water, but with infrequent moderately high energy events. • low sedimentation rate indicated by abundant head corals.
• Pleistocene sediments filling cavities in the Cayman Fm		• karsted exposure surface.

Rogers Wreck Point #3



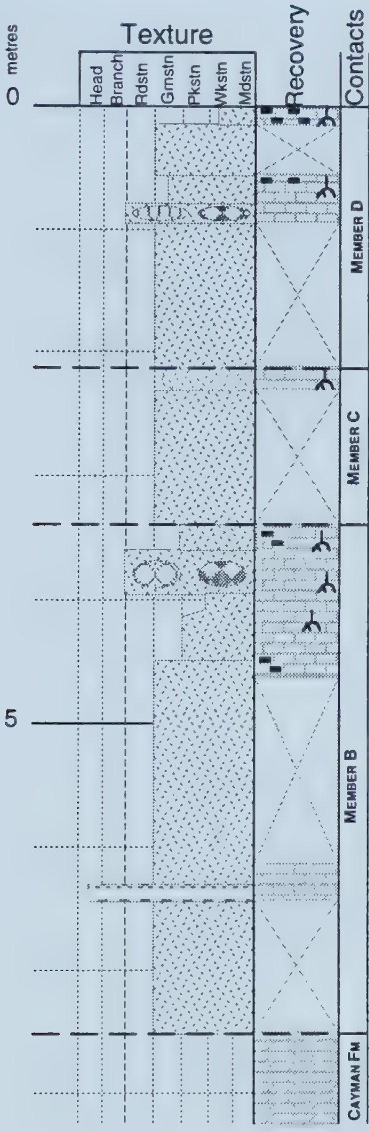
Unit	Description	Significant Features	Interpretation
Member D	• rhizoliths. • boring bivalves still present in the coral. • sand ranges from very fine-, to very coarse grain-size.	• rhizoliths. • poorly cemented sand was being washed out of the hole while drilling!	• exposure surface. • water energy too high to allow mud deposition. • high sedimentation rate (few corals).
Member C	• core well indurated. • *terra rossa* throughout, rhizoliths. • sediment locally has a nodular texture.	• *terra rossa* associated with rhizoliths. • abundant mud. • nodular texture.	• exposure surface. • quiet water, possibly microbial mats? • bioturbation.
Member B	• cracks filled with grnstn from above. • well-rounded grains • diverse assemblage of gastropods.	• mud present. • small gastropods.	• karsted surface. • quiet water. • hard substrate.
Cayman Fm			

Rogers Wreck Point #4



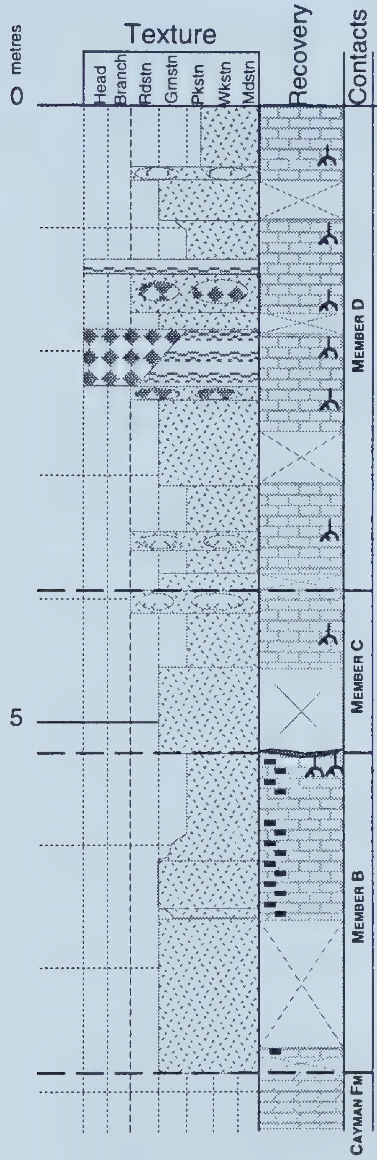
Contacts	Description	Significant Features	Interpretation
MEMBER D	• red-brown lithified soil with suspended allochems. • coral frags bored.	• soil. • rare head corals *in situ*. • mud present.	• exposure surface. • quiet water environment, possibly algal mats. • head corals growing on a coral meadow.
MEMBER C	• preserved material is well-indurated, although locally rubbly. • abundant bioerosion. • small head corals with numerous borings. • rock strongly influenced by rhizoliths.	• soil. • all detrital material.	• quiet water processes with infrequent storm events.
MEMBER B	• abundant rhizoliths; white allochems (dominantly *Halimeda*) suspended in *terra rossa*.	• *terra rossa* and rhizoliths. • abundant mud, no *in situ* organisms.	• exposure surface. • quiet water, possibly with microbial mats.
CAYMAN FM			

Rogers Wreck Point #5



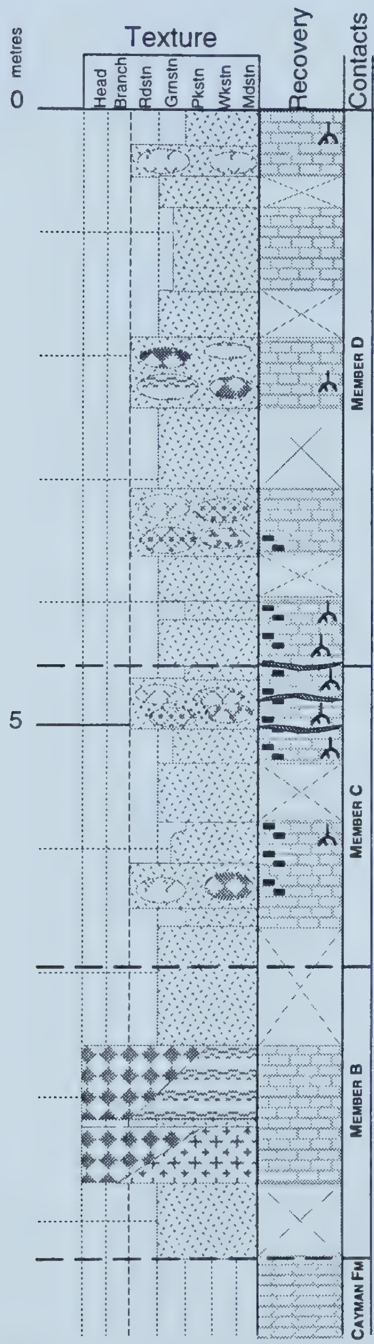
Unit	Description	Significant Features	Interpretation
Member D	• soil. • poorly indurated, rubbly.	• soil. • abundant grnstn. • rdstn consists mostly of head corals.	• exposure surface. • water energy typically too high to allow mud deposition.
Member C	• abundant *Halimeda*.	• mud. • abundant grnstn.	• dominantly mod-high energy, decrease in water energy at the top unit.
Member B	• *terra rossa* fills porosity in corals. • allochems suspended in *terra rossa*. • few frags of encrusting organisms. • base rubbly, with textures varying btwn wkstn and grnstn. • very coarse sand; poorly indurated.	• *terra rossa*. • mud. • rdstn consists mostly of head corals. • abundant grnstn.	• exposure surface. • decrease in water energy. • unsuitable conditions for coral growth, possibly due to high sed rate.
Cayman Fm	• borings with Pleistocene sed in them.		• hard substrate.

Rogers Wreck Point #6a



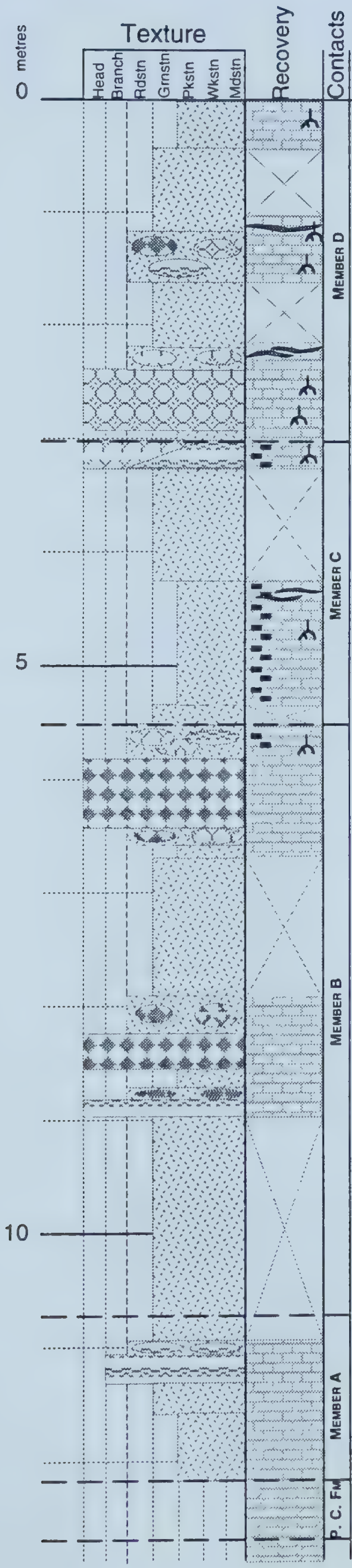
Description	Significant Features	Interpretation
• low abrasion, high degree of bioerosion,no articulation, mod fragmentation. • very thick shell frags. • "spongy" texture. • fine-grained, well-rounded allochems. • poorly indurated • allochems consist of fine to medium grained sand. • abundant *P. porites*, with few encrusters.	• rhizoliths. • greater diversity of coral species (in rubble). • no *in situ* branching corals. • mud throughout. • well-rounded grains.	• exposure surface. • dominantly quiet water environment with rare storm events (abraded grains and toppled branching corals).
• grain size decrease to lower medium. • root holes have yellow halo. • core colour varies from white to tan.	• mud.	• water energy decreases upward.
• *terra rossa* throughout this unit. • "spongy" texture. • material consists of coarse to very coarse sand.	• *terra rossa*. • mud. • abundant sand.	• exposure surface. • water energy decreases upward. • high sed rates?

Rogers Wreck Point #7



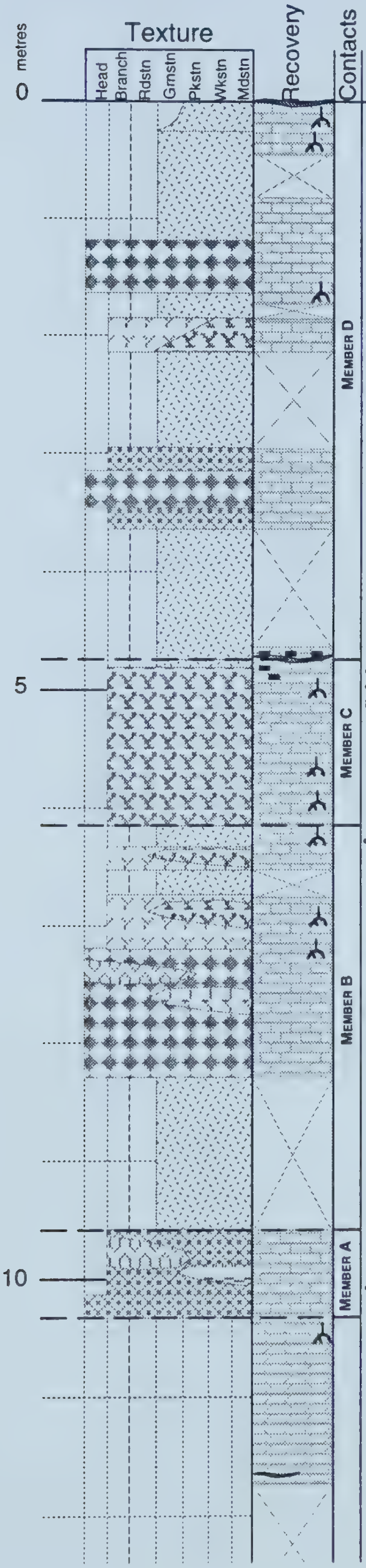
Contacts	Description	Significant Features	Interpretation
Member D	• thick, fragmented shells. • *Homotrema* on corals has a high relief.	• increasing mud content. • increasing *P. porites*. • very sandy overall.	• quiet water with high sedimentation rates, mud and *P. porites*.
	• many encrusted and bored *P. porites*. • grain size decreases from coarse to upper fine. • thick, coloured shells.		• water energy high enough to prevent deposition of mud.
	• meniscal cements • core rubbly where sand. • sed between and in coral porosity.		
	• sediment not well indurated; *Acropora* without encrusters, broken head coral, and thick shell frags with shelter porosity.	• shelter porosity and absence of encrusters on coral.	• storm event, rapid deposition.
Member C	• well-developed soil and laminated surface (caliche).	• caliche, soil, and *terra rossa*.	• exposure surface.
	• large root cast; abundant *terra rossa*.	• alternating muddy matrix with sands.	• quiet water environment with rare energy fluctuations, or the absence of mud-binding microbial mats.
	• leached shells and *Halimeda*; allochems smaller than above. • corals leached. • some "spongy" texture.		
Member B	• thick, encrusting red algae; low profile *Homotrema*.	• thick algae and low profile *Homotrema*.	
	• uniform grain size (mostly forams).	• no mud.	• high-energy, well-washed environment.
	• intra-coral seds composed mostly of encrusters; rare, high-relief *Homotrema* were sheltered.	• head corals *in situ* with sand.	
Cayman Fm			

Rogers Wreck Point #8

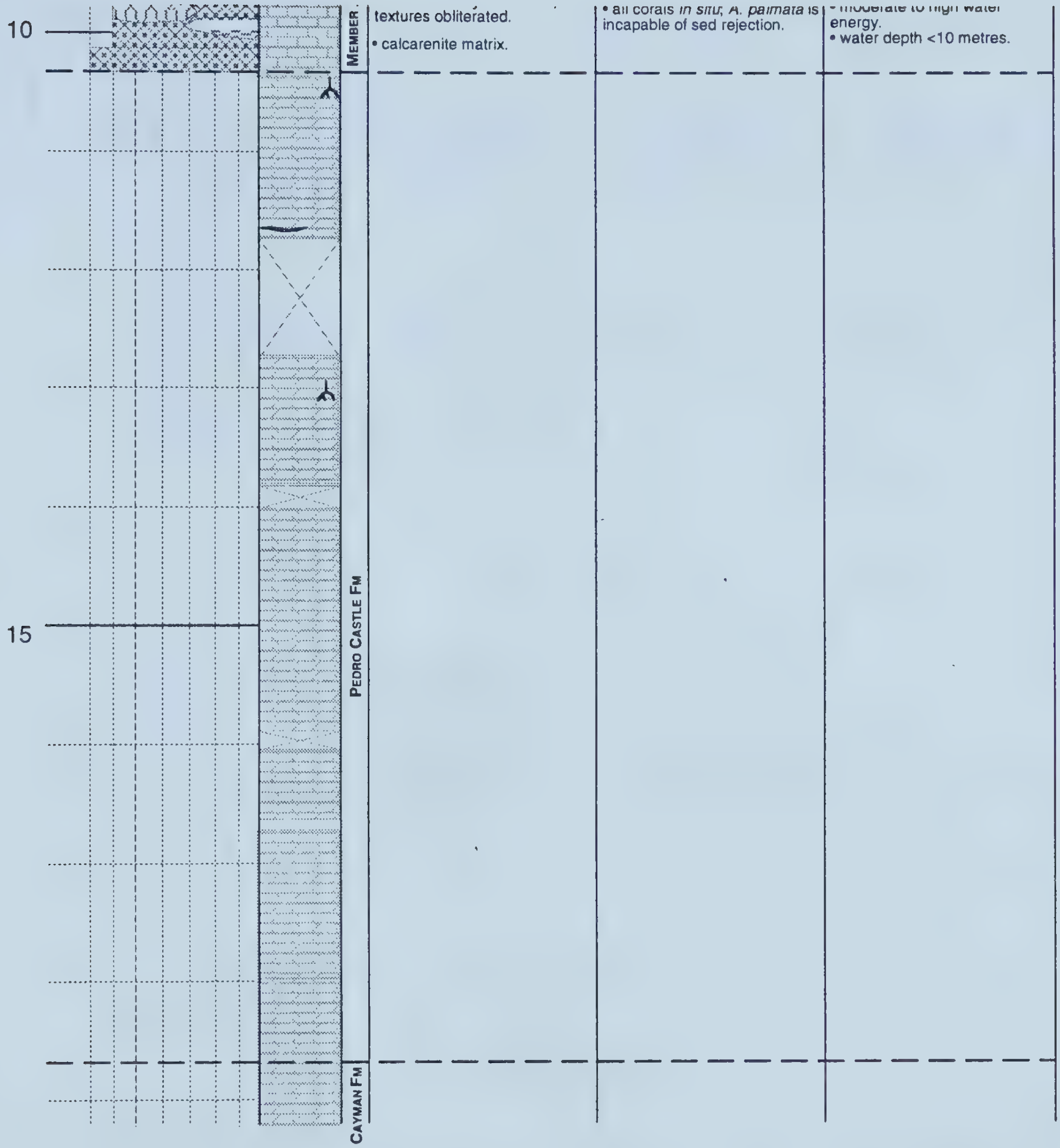


Unit	Description	Significant Features	Interpretation
Member D	• dense, brownish core lacks laminations. • abundant rhizoliths. • diagenesis has obliterated textures. • shells show the most fragmentation. • chalky but poorly indurated. • corals are bored and encrusted.	• abundant rhizoliths. • mud absent. • bioerosion.	• exposure surface. • moderate energy environment; quiet enough to allow bioerosion, but high enough to prevent mud deposition.
Member C	• *terra rossa*, grey colour. • several complex textures: grnstn and two pkstns, pkstns differentiated based on allochems (one forms pods). • *Halimeda*-foram pkstn: high abrasion, very micritized, no articulation, ~60% fragmented. • high diversity of allochems. • *terra rossa* throughout unit.	• abundant *terra rossa*. • grnstn pods in pckstn. • high abrasion and micritization.	• exposure surface. • sediment bioturbated. • higher energy. • low energy (micritization and mud). • high energy events (abrasion of grains).
Member B	• core not well cemented; "spongy" texture. • allochems too fine-grained to identify macroscopically. • grnstn btwn corals. • core has a very xtalline appearance. • thourough recrystallization; grains cannot be identified. • grains well-rounded and uniform in size.	• very little mud present. • grains well-rounded and uniform in size.	• dominantly high energy conditions (sorted, rounded grains).
Member A	• poorly indurated. • low relief encrusters.	• mud present.	• low energy.
P. C. Fm			
Cayman Fm			

Rogers Wreck Point #9



Contacts	Description	Significant Features	Interpretation
MEMBER D	• well-laminated caliche. • abundant rhizoliths. • allochems are mostly small (< 1 mm), thick shells; small gastropods? or forams? • coarser, grainier than above; sandy sed fills in borings in coral.	• caliche, rhizoliths.	• exposure surface. • water-energy high enough to prevent mud deposition.
	• abundant poorly indurated sand.	• abundant sand.	
	• corals are encrusted and bored.	• *in situ A. palmata*.	• water depth <10 metres.
MEMBER C	• caliche and *terra rossa*. • encrusted *A. cervicornis*; matrix lacks mud.	• caliche and *terra rossa*. • lack of mud; *A. cervicornis in situ*; abundance of encrusters.	• exposure surface. • moderate water-energy, probably <10 metres.
MEMBER B	• spongy texture. • thick algae on tops of *A. cervicornis*. • matrix sed appears muddy(?) with large *Halimeda*. • grains very abraded. • strong diagenesis; leaching and coarse recrystallization of *M. annularis* polyps.	• abundant and diverse *in situ* coral assemblage. • branching corals with thick algae. • grains are locally very highly abraded; mud is only a minor component. • head corals.	• increase in sedimentation rates upward (?) (head corals succeeded by branching corals). • storms, grain redistribution indicated by strong abrasion of grains.
MEMBER A	• extreme recrystallization; textures obliterated. • calcarenite matrix.	• all corals *in situ*; *A. palmata* is incapable of sed rejection.	• moderate to high water energy. • water depth <10 metres.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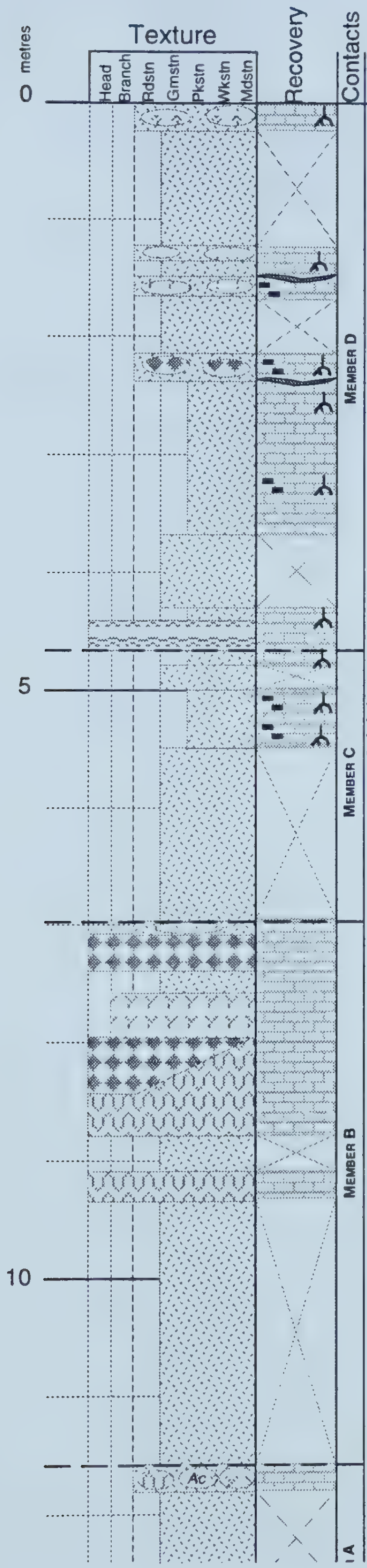
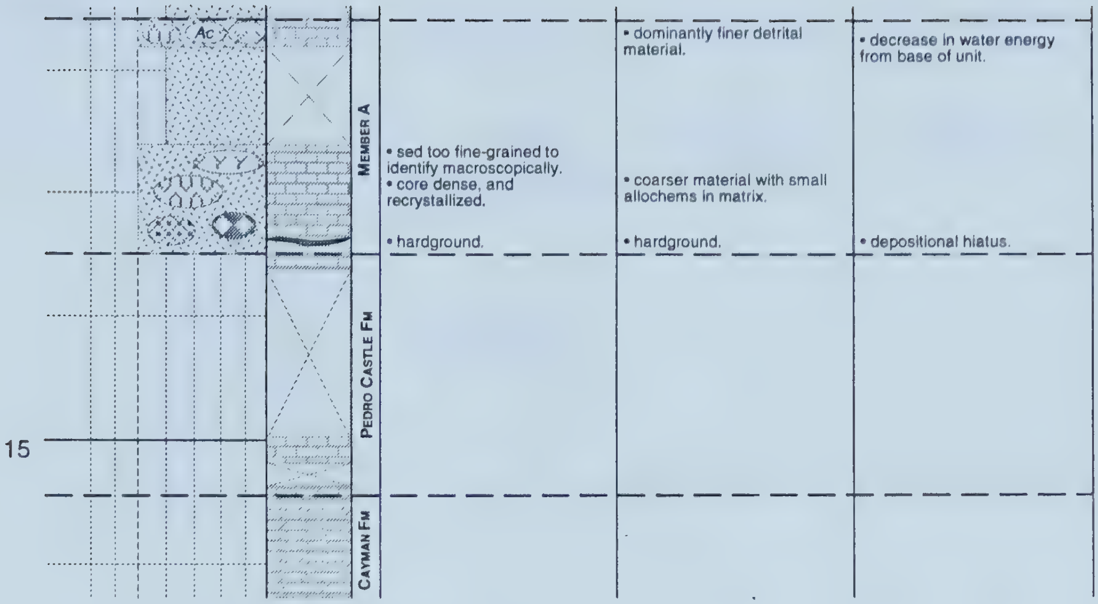
MEMBER
PEDRO CASTLE FM
CAYMAN FM
textures obliterated.
• calcarenite matrix.
• all corals in situ; A. palmata is incapable of sed rejection.
• moderate to high water energy.
• water depth <10 metres.

Rogers Wreck Point #10

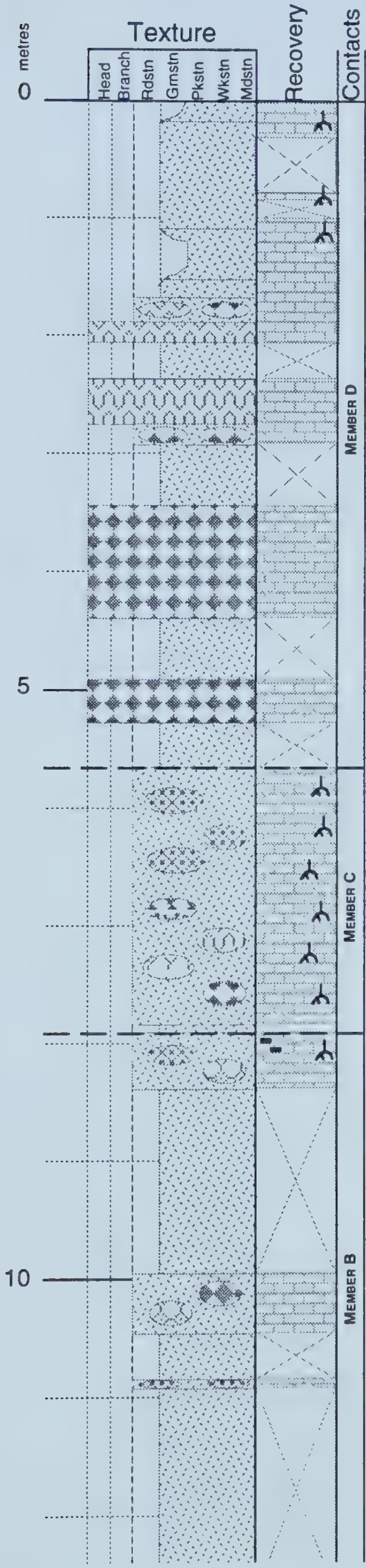


Description	Significant Features	Interpretation
• tiny rhizoliths.	• rhizoliths.	• exposure surface.
• globular *Homotrema* on corals. • *terra rossa*. • laminated surfaces.	• lots of encrusters; high relief *Homotrema*. • *terra rossa*. • laminated surfaces.	• laminations probably formed on large root casts. • higher energy.
• *terra rossa*, rhizoliths.		
	• mud.	• low energy.
• T.S.: peloidal-*Carpenteria* pkstn; high frag, abr, bioero.		
• *terra rossa* throughout.	• *terra rossa*.	• exposure surface.
• well-indurated. • *P. porites* leached. • rhizoliths filled/replaced by calcite cement.	• mostly sand in the section, but muddy section coincides with *P. porites*.	• *P. porites* likely baffled water allowing mud deposition.
• thin sed wedges between corals.		
• bored and very thickly encrusted with coralline algae.	• dominated by *in situ* head corals.	
• corals are 'encrusting' on each other; thick algae.	• diverse coral assemblage.	• low sedimentation rate and favourable conditions (lithified sands) for coral growth, diverse assemblage.
• encrusting *Carpenteria*, *Homotrema*, and thick red algae.		
	• sand.	
	• dominantly finer detrital material.	• decrease in water energy from base of unit.

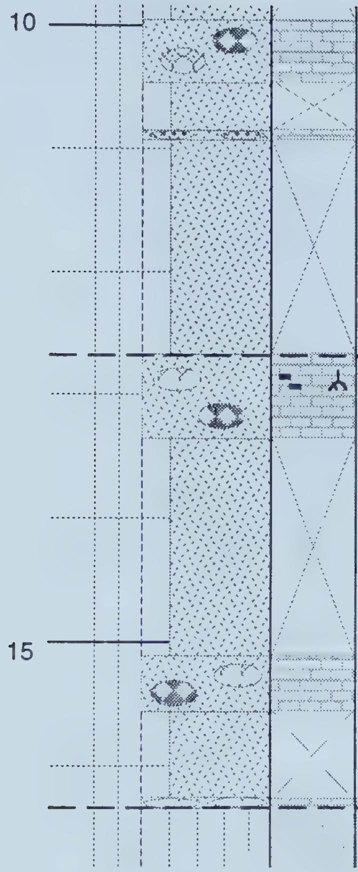


Ac
Member A
• sed too fine-grained to identify macroscopically.
• core dense, and recrystallized.
• hardground.
• dominantly finer detrital material.
• coarser material with small allochems in matrix.
• hardground.
• decrease in water energy from base of unit.
• depositional hiatus.
15
Pedro Castle Fm
Cayman Fm

Rogers Wreck Point #11

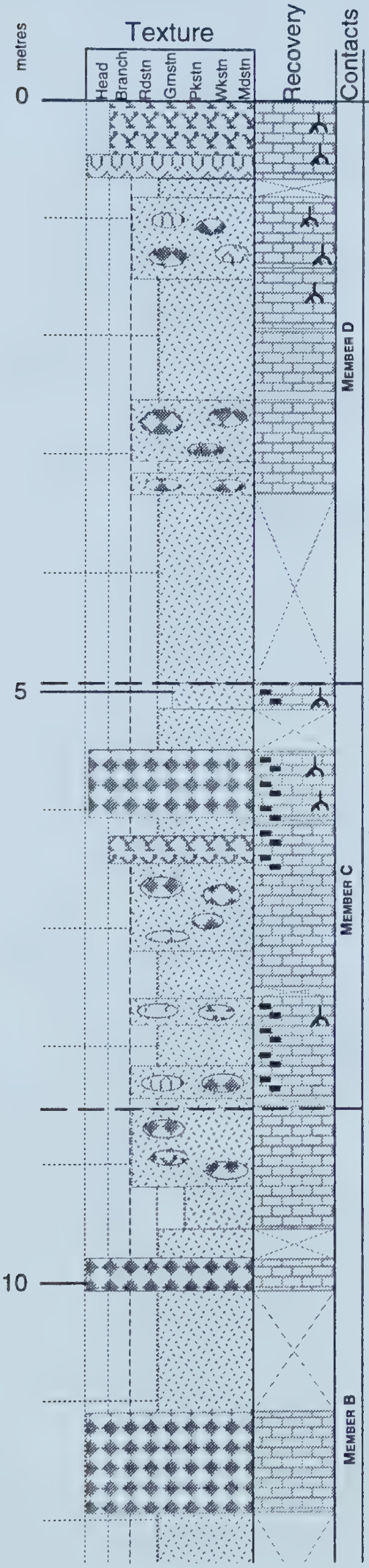


Member	Description	Significant Features	Interpretation
Member D	• seds altered by calicretization-difficult to assess characteristics. • *Halimeda* abundant throughout this core. • corals all very bored. • entire unit encrusted and bored.	• entire unit alternating *in situ* head corals and sandy sediment.	• water energy high enough to prevent the deposition of mud.
Member C	• T.S.: mixed pkstn and grnstn; pkstn has larger allochems. • sand-sized material too fine to identify in core. • beds of shell, red-algae, and *Halimeda*-rich material. • generally low abrasion, high degree of bioerosion, ~25% fragmented.	• dominated by coarse detrital material; abundant boulders of *A. palmata*. • most 'matrix' material small, with abundant bioerosion and low abrasion.	• low-moderate energy, probably the back of the reef crest.
Member B	• *terra rossa* and root boring; textures obscured by caliche.	• *terra rossa*, root boring, and caliche.	• exposure surface.
		• abundant sand with rare rudstones.	• storm events, rudstones form a rubble pavement.
	• corals well-preserved, but fragile because still have framework porosity.	• mud absent.	• water energy high enough to prevent deposition of mud.

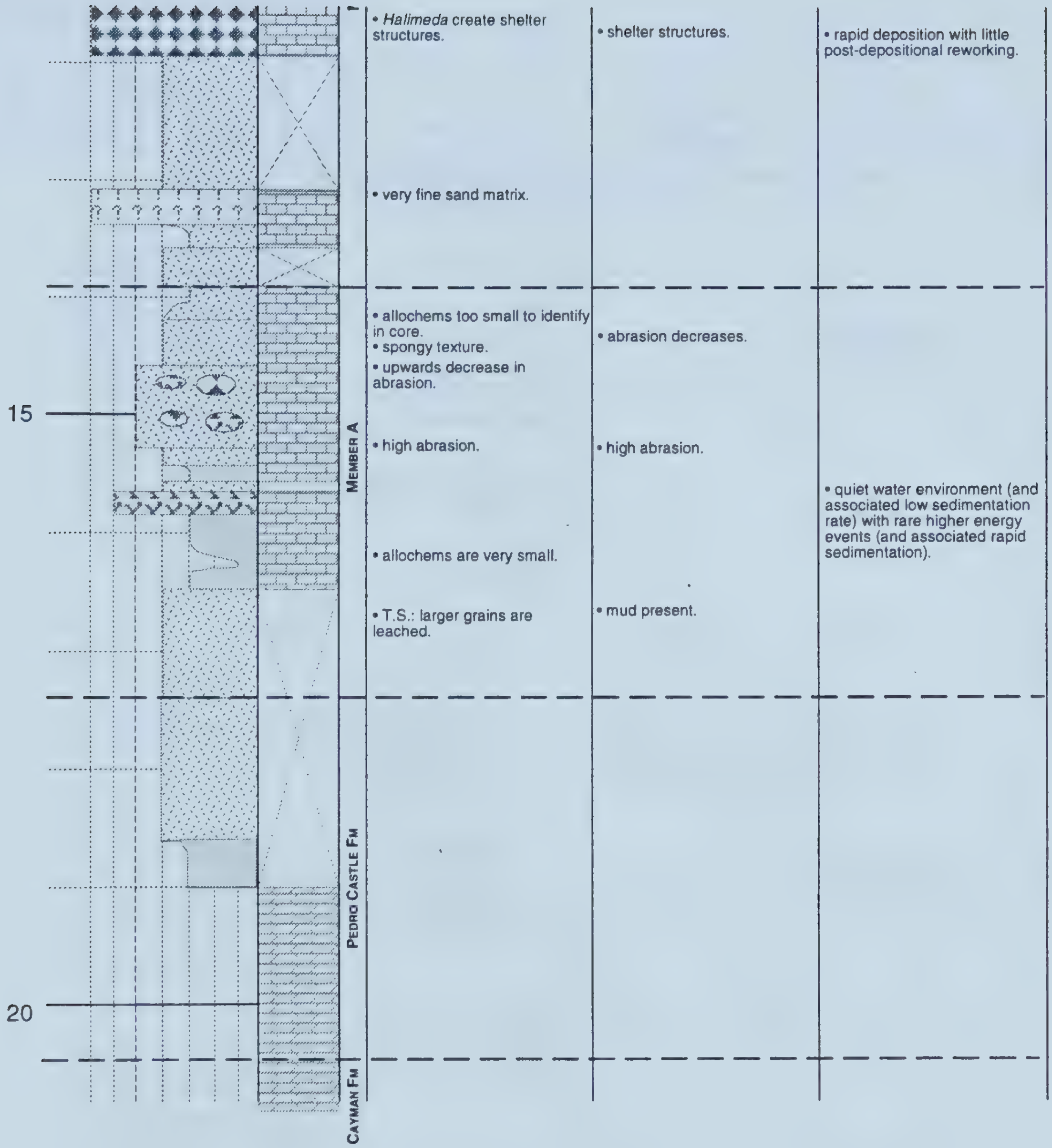


Member B	• corals well-preserved, but fragile because still have framework porosity.	• mud absent.	• water energy high enough to prevent deposition of mud.
Member A	• coral rubble, pieces < 5 cm. • grnstn to pkstn/wkstn. • grnstns have well-developed cement crusts. • abundant borings partly filled with sediment.	• mud in the rdstns. • dominantly sand-sized material with episodic coarser coral rubble.	• storm events, rudstones form a rubble pavement. • storm events, rudstones form a rubble pavement. • water energy high enough to prevent deposition of mud.
Pedro Castle Fm			

Rogers Wreck Point #13

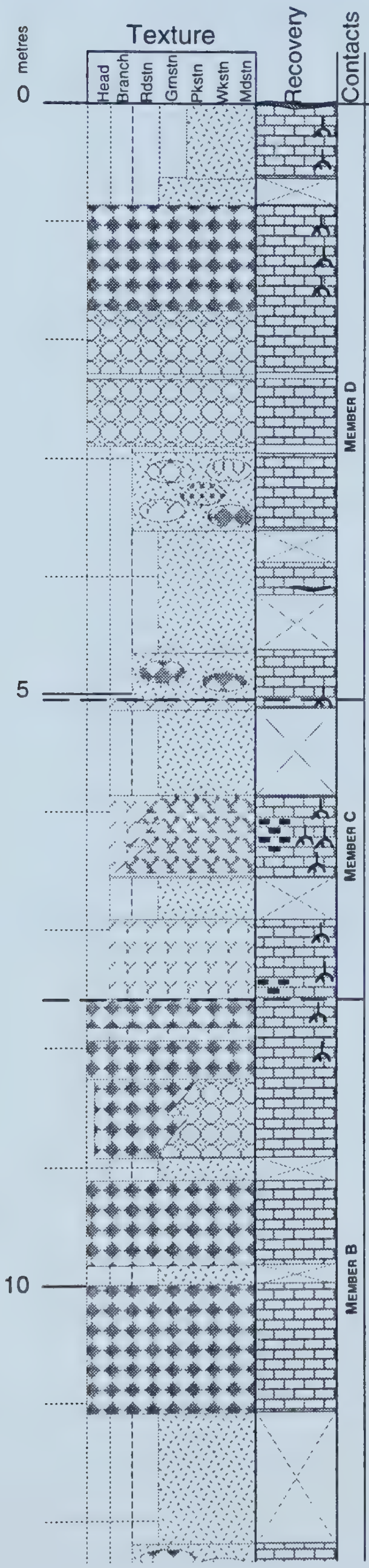


Member	Description	Significant Features	Interpretation
Member D	• encrusted corals. • T.S.: peloidal pkstn; abr (?); high bioer; low artic; high frag'n.	• pkstn matrix, high bioerosion and fragmentation.	
	• sed acting as matrix around headstone rubble is not well cemented; med sand size; 0% art, 80% abra, > 70% encrusting on corals. • some very thick bivalves, fragmented.	• grnstn matrix, 80% abraded, abundant encrusters, thick bivalve shells, all fragmented.	
		• pkstn matrix, abundant micritization, some thick pelecypod shells.	• low-moderate energy environment, but nearby a high energy environment (encrusters, abrasion, and fragments).
	• T.S.: pkstn; grains v micritized extensive leaching. • thick pelecypod shell (~!cm).	• pkstn to poorly-washed grnstn, low abrasion, high bioerosion fragmentation.	
	• T.S.: pkstn to poorly-washed grnstn; low abr, high bioer, high frag'n; extensive leaching of allochems + matirx.		
Member C	• *terra rossa.*	• *terra rossa.*	• exposure surface.
	• shells thin, small, and delicate.	• delicate shells.	• lower energy with episodic high energy events.
	• coral encrusted, but leached.	• encrusted corals.	
	• T.S.: grnstn to poorly-washed grnstn; low abr, high bioer, low art; grains v micritized.	• low abrasion, high micritization; grnstn to poorly-washed grnstn.	
	• all grains in sands are well-rounded.	• abraded grains.	• higher energy environment.
Member B	• pkstn to grnstn matrix.	• matrix varies from pkstn to grnstn.	• sediment mixing by infaunal organisms.
	• mud matrix.	• mud present.	
			• frequent fluctuations from low to high energy environments.
	• mud present.		
	• *Halimeda* create shelter structures.	• shelter structures.	• rapid deposition with little post-depositional reworking.

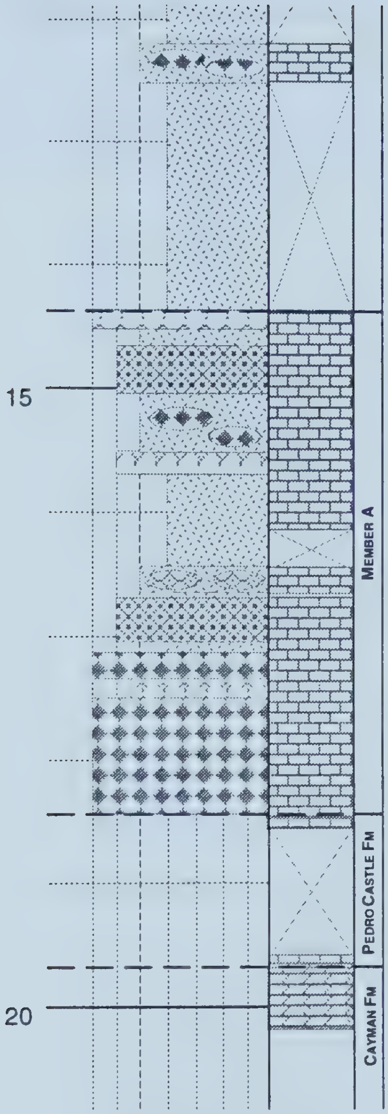


15
20
Member A
Pedro Castle Fm
Cayman Fm
• *Halimeda* create shelter structures.
• very fine sand matrix.
• allochems too small to identify in core.
• spongy texture.
• upwards decrease in abrasion.
• high abrasion.
• allochems are very small.
• T.S.: larger grains are leached.
• shelter structures.
• abrasion decreases.
• high abrasion.
• mud present.
• rapid deposition with little post-depositional reworking.
• quiet water environment (and associated low sedimentation rate) with rare higher energy events (and associated rapid sedimentation).

Rogers Wreck Point #14

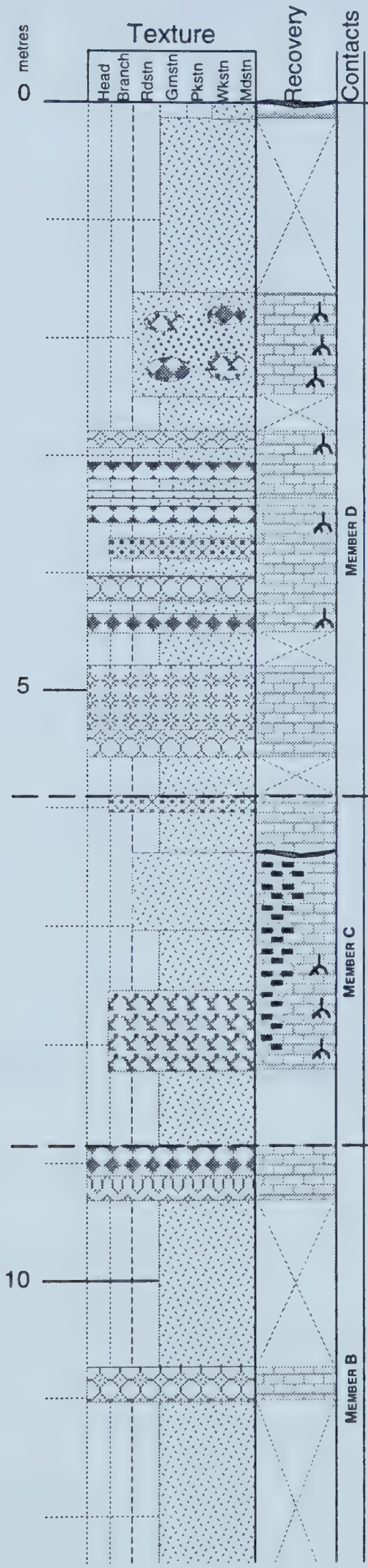


Description	Significant Features	Interpretation
• T.S.: *Carpenteria*-coral pkstn; low abrasion, high bioerosion, no articulation, high fragmentation.	• low abrasion, high bioerosion, no articulation, high fragmentation.	• low energy.
• *M. annularis* heads, 10-15 cm size.	• small coral heads.	
• corals brown along edges.		
• very coarse sand.	• very coarse sand.	• small patch reef with sediment reworking by infaunal organisms.
• some areas are dense, some have nodular appearance with coated grains.	• nodular texture	
• matrix obliterated, locally very dense.		
• locally the core is crumbly; where indurated, core looks chalky; some grains coated.		
• core varies between well-indurated to very crumbly and obliterated.		
• *entobia* in coral frags.	• sands and rdstns.	• higher energy.
• fragile, crumbly. • pronounced gray discolouration.	• gray discolouration.	• associated with soil development.
• distinct break in core where changes from grnstn with porosity to very dense material with rhizoliths.	• dense core and rhizoliths. • branching corals and grnstns.	• exposure surface.
• shells, corals leached. • *A. cervicornis* bored and encrusted. • abundant *terra rossa*. • allochems small, leached? • 1 cm wide areas of powdery-looking texture.	• corals bored and encrusted.	• moderate-low energy environment with thickets of branching corals.
• T.S.: fine-grained grnstn with large encrusters; low abrasion, high bioerosion, no articulation.	• low abrasion, high bioerosion, no articulation.	
• grain size increase; shells more robust.	• abundant corals.	
• texture obscured, cannot identify grains macroscopically.	• dominantly head corals.	• patch reefs, lower sedimentation rates.
• dense white core.		
• core fragile where coral present.		
• shells leached.		
	• sand.	• episodic storm events, high sedimentation rates.
• rubbly core.		• reworked shell material,

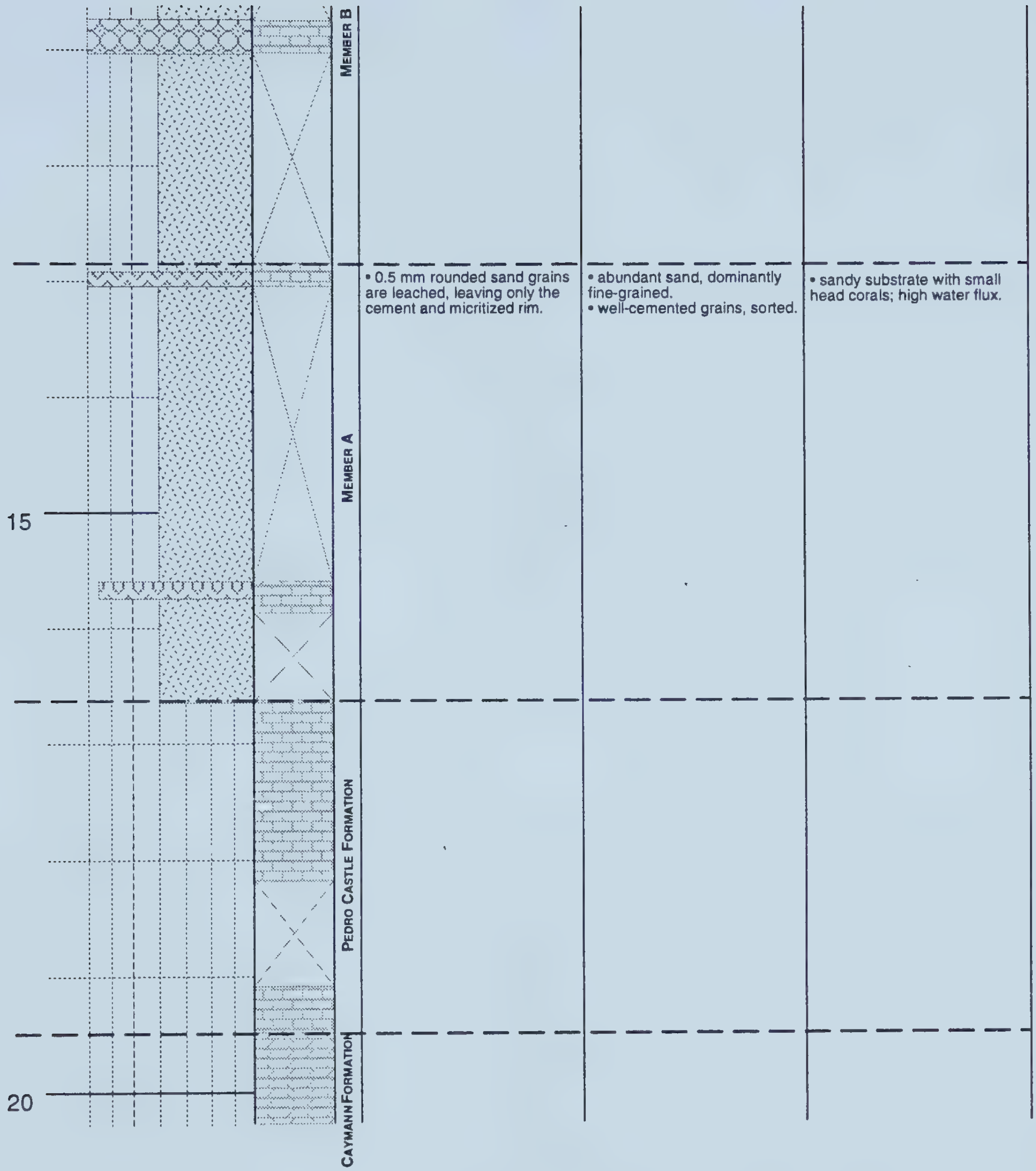


• rubbly core. • bivalves filled with mud.	• bivalves filled with mud.	• reworked shell material, originally from lower energy environment.
• core well cemented, bladed circumgranular. • small dissolution cavities?	• well cemented. • *in situ* branching corals (*A. palmata*).	• high water flux through sediments. • water depths probably <10 metres.
• *entobia* abundant in branching corals.	• *entobia* abundant in branching corals.	• moderate water energy?
• selective leaching of *Halimeda* and gastropods.	• *in situ* head corals.	

Rogers Wreck Point #15



Unit	Description	Significant Features	Interpretation
Member D	• very dense, thin brown laminations on surface of the core.	• caliche.	• exposure surface.
Member D		• sand.	
Member D			• higher water energy, higher sedimentation rates.
Member D	• alteration makes matrix difficult to identify. • abundant encrusting material on branching coral. • sand fragments rounded.		
Member D	• alternating head corals (<10 cm high) and sand.		
Member D	• calcretization has obliterated matrix, cannot identify smaller allochems.		
Member D		• alternating head corals (<10 cm high) and sand.	• coral meadow, small corals.
Member D	• alternating head corals (<10 cm high) and sand.		
Member C	• coral bored by bivalves and encrusted with algae and forams; small gastropods are abundant.	• pervasive bioerosion.	
Member C	• coarse sed; thick shells. • *terra rossa* abundant. • roots avoid coral fragments, are preferentially in sandy material.	• abundant *terra rossa*.	• exposure surface; laminations probably developed around a root.
Member C	• branching coral fragments leached. • thick reaction rind around *M. annularis* fragments. • corals encrusted with algae and forams, and bored by sponge. • red algae stand out because surrounding matrix is brown.		• moderately-high energy environment with thickets of branching corals growing on a sandy substrate.
Member B	• poorly indurated sandy material, leached shells. • clear cement lines cavities which may be borings (1-2 mm).	• abundant sand with minor head corals.	• coral meadow in moderate energy conditions, small corals.



Member B
Member A
Pedro Castle Formation
Cayman Formation
15
20
• 0.5 mm rounded sand grains are leached, leaving only the cement and micritized rim.
• abundant sand, dominantly fine-grained.
• well-cemented grains, sorted.
• sandy substrate with small head corals; high water flux.